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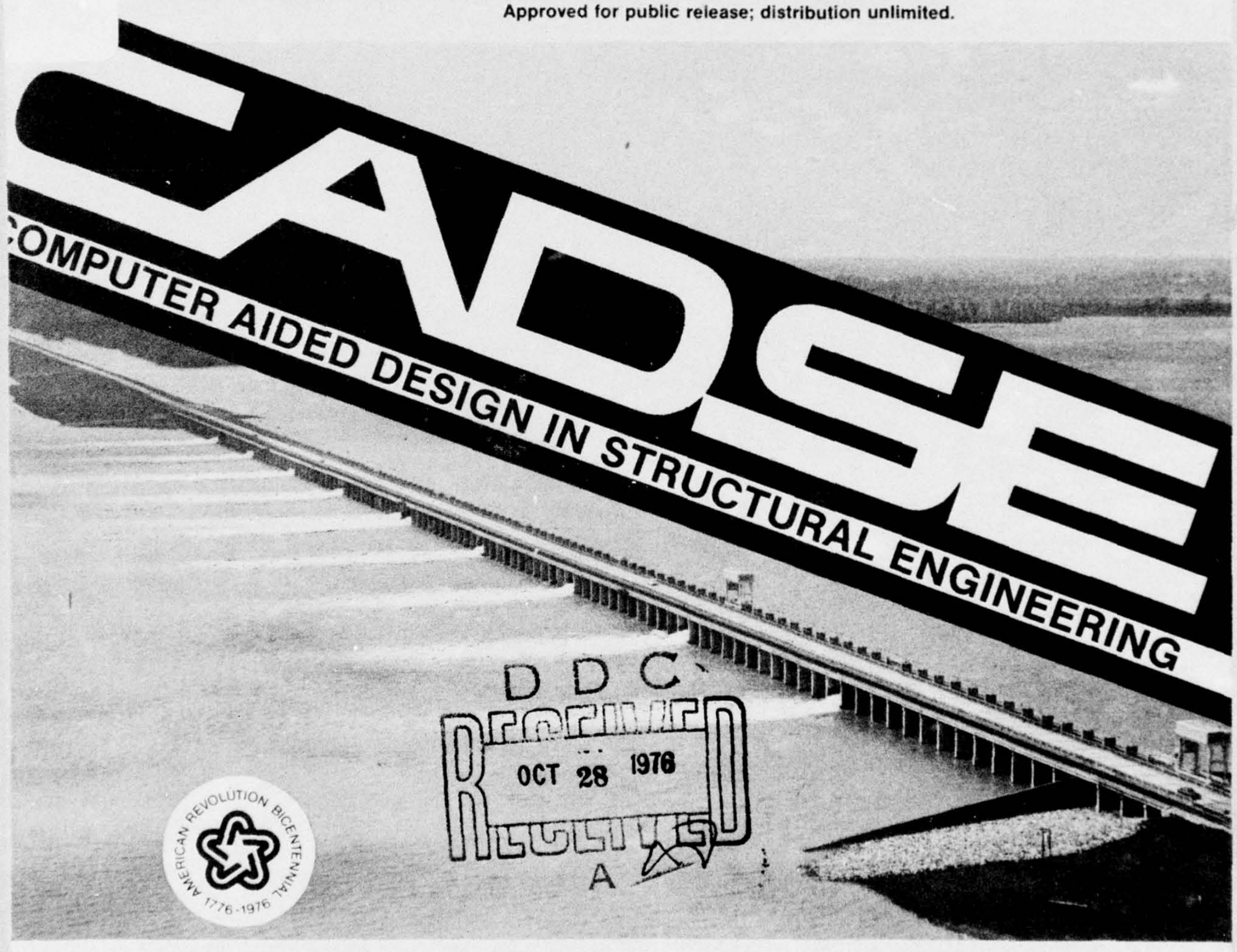
CORPS-WIDE CONFERENCE ON

COMPUTER AIDED DESIGN IN STRUCTURAL ENGINEERING

22-26 September 1975

VOLUME III
INVITED SPEECHES and TECHNICAL PRESENTATIONS

Edited by N. RADHAKRISHNAN



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Prepared for Office, Chief of Engineers, U. S. Army
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August 1976

by Automatic Data Processing Center
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Mr. Charles Corns, in his speech on STRUCTURAL DESIGN IN THE CORPS, spoke about the training of structural engineers, the responsibility of Office, Chief of Engineers (OCE), for issuing technical guidance to field offices, and the structural engineering research program. COL Patrick Marks, discussing COMPUTER SUPPORT FOR ENGINEERS, stressed OCE's willingness to help with hardware procurement, software support, research support dissemination efforts, contractual support, and ADP planning. Mr. Corns' second speech,

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20. ABSTRACT (Continued).

THE ROLE OF COMPUTERS IN CIVIL WORKS DESIGN, gave the historical background for using the computer for structural analysis, surveyed the current Civil Works development program for computer use, and discussed some areas where computer analysis has vastly improved structural design. Mr. William D. Ashton, in his speech on COMPUTER-AIDED BRIDGE DESIGN, told how the Rock Island District (RID) has greatly increased its design efficiency and reduced design time and costs by using the computer. He discussed several specific projects and evaluated some of the programs RID used in its design. Mr. James Cheek, in his talk, ENGINEERING COMPUTER GRAPHICS, gave the history of the WES ADPC computer graphics capability. Dr. N. Radhakrishnan, discussed SOME RECENT APPLICATIONS OF THE FINITE ELEMENT METHOD IN CORPS' WORK. These applications included analyses of U-frame locks, dams, buried cylinders, distressed structures, pavement, slope stability, deep foundations, seepage, creep, and consolidation. The finite element method has also been used to evaluate laboratory and field tests and for dynamic and earthquake analyses. Mr. Richard Delyea presented the Federal Construction Council's System called FACTS. (FACTS is the acronym for Federal Agencies Computer Time-Sharing System.) FACTS is an extensive library of fully documented, easily used computer programs dealing with a wide variety of construction related engineering problems. A similar library called Conversationally Oriented Real-Time Programming System (CORPS) is maintained by the Corps of Engineers at WES.

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PREFACE

In December 1974, the Automatic Data Processing (ADP) Center, U. S. Army Engineer Waterways Experiment Station (WES), submitted a proposal to conduct a Corps-wide Conference on Computer-Aided Design in Structural Engineering (CADSE) to the Office, Chief of Engineers (OCE). OCE approved the proposal and efforts were started in February 1975 to conduct this Conference. The Conference was held in New Orleans, Louisiana, 22-26 September 1975 and was attended by 175 engineers from 48 Corps field offices, OCE, Construction Engineering Research Laboratory (CERL), and WES.

This volume contains papers from the Invited Speeches and Technical Presentations. These presentations were made by Mr. Charles F. Corns, Chief, Structures Branch, OCE; COL Patrick W. Marks, Chief, Engineering Information and Data Systems Office; Mr. William D. Ashton, Chief, Structural Section, Rock Island District; Mr. James B. Cheek, Jr., Chief, Computer Analysis Branch, WES; Dr. N. Radhakrishnan, Special Technical Assistant, ADPC, WES; and Mr. Richard Delyea, Chief, Computation and Analysis Branch, OCE.

The Conference was successful due to the efforts of a multitude of people. The roles they played were different but they were all directed toward making a concept on "instant dissemination" work. The Organizing Committee for the Conference consisted of:

COL G. H. Hilt, WES
Mr. F. R. Brown, WES
Mr. D. L. Neumann, WES
Mr. J. B. Cheek, Jr., WES
Dr. N. Radhakrishnan, WES--Conference Coordinator
Mr. W. A. Price, WES
Mr. G. S. Hyde, WES
Mr. D. R. Dressler, LMVD
Mr. W. B. Dodd, LMNDE
Ms. E. Smith, LMNDE
Mr. L. H. Manson, LMNDE

An OCE Coordinating Committee also worked enthusiastically to ensure the success of the Conference. This Committee consisted of:

Mr. C. F. Corns

Mr. R. L. Delyea

Mr. R. F. Malm, OCE Coordinator

Mr. L. G. Guthrie

Mr. D. B. Baldwin

Mr. R. A. McMurrer

The U. S. Army Engineer District, New Orleans, did a remarkable job in playing host to the Conference.

There were 13 Division speakers, 25 moderators, two invited speakers, four technical speakers, and ten session chairmen, who shared the technical load of the Conference. Also, eight computer vendors showed their wares to the participants.

The editor would like to thank all the individuals who served on the committees and the speakers and the moderators for sharing their time and thoughts. Without them the Conference would not have been the success it was. Mr. Dressler, LMVD, and Mr. Price, WES, are specially thanked for their technical guidance and assistance.

This report was edited by Dr. N. Radhakrishnan, Research Civil Engineer, Computer Analysis Branch (CAB) and Special Technical Assistant, ADP Center, under the direct supervision of Mr. J. B. Cheek, Jr., Chief, CAB, ADP Center, and the general supervision of Mr. D. L. Neumann, Chief, ADP Center.

The Director of WES during the Conference and the preparation of this report was COL G. H. Hilt, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

CONTENTS

STRUCTURAL DESIGN IN THE CORPS

by

Charles F. Corns*

I am extremely happy to have the opportunity of addressing this group of Corps engineers. This is probably the largest single gathering of structural engineers with which I have had the privilege to meet since assuming my present position. I have been asked to speak tomorrow as proxy for Mr. Homer Willis, Chief of the Engineering Division, in the OCE Directorate of Civil Works, on the subject of the role of computers in Civil Works design. So I will try to avoid any comprehensive discussion of computers today.

I am not quite sure whom I represent today, but remarks have been dropped that would indicate that I might be standing in for the Chief of Engineers himself. Whoever it is, I will try to be a worthy substitute.

Today, I will review some significant developments in structural engineering in the Corps, discussing the major areas of (a) training, (b) technical guidance, and (c) research. First, however, I wish to express my personal appreciation to COL Rush and the New Orleans District for hosting this conference and to the representatives of the Waterways Experiment Station (WES) for their excellent planning efforts. Particularly, I wish to commend Dr. Radhakrishnan, Don Neumann, Bill Price, and James Cheek of WES and Don Dressler of the Lower Mississippi Valley Division (LMVD). I believe this conference has received the most intensive planning effort of any Corps conference with which I have had the privilege of being associated.

With respect to the general status of structural engineering in the Corps, let me say that we are now in a transitional period. We have reached a stage where it is essential to both the efficiency and capability of performing our work that the computer be used. But it must be used wisely, efficiently, and competently. I will have more to say on this point tomorrow.

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* Chief, Structures Branch, Engineering Division, Civil Works Directorate, Office, Chief of Engineers (OCE).

During recent years we have seen a trend developing for the decentralization of engineering functions and responsibilities within the Corps. In Civil Works the approvals of such documents as feature design memoranda and inspection reports are now possible at the division office level. This trend will probably continue, transforming the principal engineering design function in the Civil Works Directorate, OCE, from one of design approval to one of assistance. While we have always considered our principal purpose to be that of helping the field, that help was underpinned by the lengthy, time-consuming review work necessary to execute formal approval actions. Our future design reviews, those for which the divisions have approval authority, will be less in depth and more geared to the objectives of keeping informed and searching for unprecedented or unique problems.

Such delegation of new approval authority to the division means that division offices must become adequately and competently staffed and that OCE must improve its technical guidance to the field. It also follows that design offices must maintain good engineering capability and keep abreast of new developments. This includes the adequate training of our structural engineers.

The area of training is one which we in OCE have been trying to promote for several years. The maintenance of a program of continuing education is essential to the performance of our mission. Complexity and change are predominant in our present day engineering, and technical obsolescence is now being measured by a space of only a few short years instead of a lifetime, as it was a relatively short time ago. Thus continuing education is no longer a luxury but an absolute necessity for continued personnel and organizational viability. We are obliged to seek every opportunity to maintain and improve our competence as engineers.

The establishment of a career plan for each individual engineer in the Corps is essential. Back in 1969 we issued guidance for training and development of engineers with the issuance of ER 350-1-410. Appendix IV to that ER outlines a training and development program for structural engineers. Three program groups, designated A, B, and C, were

established. Group A was to include those engineers with less than 10 yr experience; Group B to include those with Masters Degrees, or new Corps employees with 5 yr experience and a Bachelors Degree; and Group C consisted of Senior Engineers (those with more than 10 yr service, and Chiefs of Sections and Branches).

Included in this guidance were the following suggested principal types of training: (a) on-the-job training to develop experience in all types of Corps of Engineers structures, including rotational assignments; (b) the attendance of selected employees at a 1-yr full-time university course leading to a Masters Degree under the Advanced Studies Program; (c) the attendance at periodic inspections of major projects; (d) academic study at short- or full-time courses of recommended subjects; and (e) training in supervisory and management skills. The appendix lists specific subject matters which structural engineers should include in their training plans.

The appendix also reminds us that computer technology is now a prominent, essential part of the structural design process and that young engineers frequently have greater capability in computer methods for structural analyses than supervisors and other senior engineers; therefore, it is essential that training include the updating of older engineers in computer methods.

We have not as yet made a detailed follow-up survey to determine how earnestly this guidance is being followed. I suspect, however, that it is not being used to the extent intended. We do receive an annual report on Civil Works training from our Office of Staffing and Management which reports on the Advanced Study Program and certain short term training courses conducted at Corps facilities, but we do not receive a complete summary on individual training and development. With respect to the Advanced Study Program, of the 42 participants during FY 75, 4 were structural engineers. Twenty-four others were listed as civil engineers and some of these may be primarily structurals.

I plan to develop a system to keep better track of training accomplishments for structural engineers throughout the Corps. My first step in developing such a system is to inventory and identify all

structural engineers. I have asked our Office of Civilian Personnel to furnish me a computer printout of Corps structural engineers which will be based on experience codes. Recognizing that such a list may not be all-inclusive because many structural engineers are serving under the position title of "Civil Engineer," we will ask each field office to review and confirm that portion applicable to them. Such a listing, if kept current, will help us in OCE to keep better informed on training activities, locations of personnel, and progress of individual careers. Such information will be invaluable to our efforts in planning training courses and at times when we are asked to locate possible candidates for position vacancies.

While I am on the subject of training, I should mention the current, concentrated effort to improve the skills of Corps personnel in the area of earthquake engineering. The availability of new technology for making dynamic response analyses of hydraulic structures obligates us to update our current practices and criteria. We are now formulating Corps-wide guidance which will discuss seismic design concepts and give direction for the design of new dams and the evaluation of certain existing dams. I will discuss this in greater depth later.

To meet the need for performing dynamic response analyses, a series of training sessions are being conducted. Several special lecture courses have already been completed. These were those given by Professor Seed principally to soil mechanics engineers. Similar courses specializing in concrete structures are planned for next year. A two-week course on fundamentals of dynamics was recently conducted at the WES in July and August of this year. Thirty-five engineers attended. The same course will be conducted again in December of this year.

The course on fundamentals of dynamic analyses is a preparatory course for later courses, scheduled for next year, which will deal specifically with the seismic design and analysis of concrete hydraulic structures. We feel that the preparatory course on fundamentals will be beneficial to older engineers who were not exposed to dynamics courses in school and also to many of the younger engineers who have never had the opportunity to practice such school instruction.

Next year's courses will cover such subjects as earthquake characteristics, selection of design earthquake, seismic instrumentation, and the analysis and design of earthquake resistant concrete dams, intake towers, and possible other hydraulic structures. The instructors for these courses, as now seen, will be professors from the University of California at Berkeley and the University of Illinois, and structural research engineers from WES.

So much for training. I would now like to discuss technical guidance.

The issuance of engineering manuals, guide specifications, and other design instructions, such as engineer technical letters, is one of OCE's most important functions, if not the most important, in my view. We have not performed in this regard in the past as well as I would have liked, due principally to the pressure of review work and other special assignments such as the Corps work pursuant to P.L. 92-367, the National Dam Inspection Act. The Structural Branch was assigned responsibility for managing that program.

With the foreseen reduction of our review work load, I hope to devote greater attention to the manual program. We have several manuals currently under revision or development:

A manual, EM 1110-2-2901, Tunnels and Shafts in Rock. A draft was distributed for field use and comments in December 1973 and will be published during the current fiscal year. The Omaha District prepared the draft of the tunnel manual.

A manual, EM 1110-2-2603, Lock Gates. The Mobile District is preparing a preliminary draft of this new manual. The draft is scheduled for distribution to field offices for comment prior to July 1976.

A manual, EM 1110-2-2502, Retaining Walls. The WES is drafting a revision of this manual which is scheduled for completion during Fiscal Year 1977.

A Flood Wall Manual. A revised flood wall manual is currently being prepared. The preliminary draft was prepared by the Ohio River Division and we in OCE incorporated extensive revisions before issuance for field review. The review period has just now been completed and

considerable revisions may yet be necessary based on the comments received.

A manual, EM 1110-2-2906, Design of Pile Structures and Foundations. Our work on the sheet pile portion of this manual has been seriously delayed due to pressure of other work but we hope to publish the manual before December of 1976. A major problem with this manual has been the resolution of many controversial and conflicting comments received during the draft review.

Other manuals proposed for revision during the next 2 yr include the Paint Manual, Gravity Dam Manual, Planning and Design of Navigation Locks, Working Stresses for Structural Design, and Planning and Design of Hydroelectric Power Plant Structures.

Two additional new manuals are planned for initiation in the near future. One will cover lock valves and the other will be on Intake Gates and Bulkheads.

You may ask why, in view of the present trend toward fewer new big dam and river navigation projects that I am placing such emphasis on developing new and revising existing engineering manuals pertaining to water resources construction. While it is true that the emphasis on seeking nonstructural solutions to flood control problems and the impact of the ecology movement have substantially affected the water resources construction program, I do not foresee the complete oblivion of water project construction. There is presently a backlog of some 300 major projects, with a total estimated construction cost of 11 billion dollars, authorized by the Congress and awaiting appropriations. Additional projects are certain to be authorized. Furthermore, nonstructural solutions will not be the answer to all water problems. As General Morris, the Deputy Chief of Engineers, recently remarked during a press interview, another drouth of the kind which occurred during the dust bowl thirties would make the energy crisis look like a parlor game. Such an event would certainly focus national attention again to the benefits of water storage. Speaking of the energy crisis, the search for new and firmer energy sources will possibly result in the development of new hydroelectric power projects, particularly as sources for peaking power.

I previously mentioned our efforts to develop new guidance on earthquake engineering. Traditionally, we have employed the equivalent static load method in the analysis and design of hydraulic structures for seismic loads; in recent years we have been pursuing programs to develop more rational methods. Two events have had a major impact on the development and use of dynamic response analyses in dam engineering. These were the Koyna, India, earthquake of 11 December 1967, and the San Fernando, California, earthquake of 9 February 1971. The Koyna earthquake caused significant structural damage to Koyna Dam, a 280-ft-high concrete gravity structure, which required very extensive strengthening measures. The near-failure of the Lower Van Norman Dam during the San Fernando earthquake has been widely publicized and was the incentive for a reevaluation of the seismic stability of all dams in California under the state's supervisory control. The Corps conducted a seismic stability investigation of two hydraulic fill dams, the Fort Peck and Sardis Dams, due to this event. The assessments of the Koyna and Lower Van Norman events have produced valuable contributions to the development of methodologies for dynamic analysis of dam structures.

Within a period of 4 to 6 weeks we hope to issue an engineer technical letter (ETL) which will discuss seismic design concepts and provide general guidance for the design of new dams and the evaluation of existing dams. The ETL will issue a new seismic risk map, which revises the ESSA/Coast and Geodetic Survey map issued by ETL 1110-2-109 of 21 October 1970, by including a new Zone 4. Zone 4 is an area established within a boundary of about 25 miles from active great-fault systems. Most of California, and parts of Nevada and Alaska are situated in Zone 4. New designs must continue to meet requirements of the seismic coefficient method. In addition, structures in seismic Zone 4, and those in Zone 3, where a foundation liquefaction potential exists, will be analyzed by dynamic response procedures. With respect to existing structures, we plan to require a seismic stability investigation using dynamic response techniques on all dams in Zone 4 whose failure would endanger lives or cause substantial property damage. A dynamic response investigation will also be required for Zone 3 dams, similarly situated,

where potential liquefaction is present.

The third area which I wish to talk about concerns research. When I assumed my present position in 1965 the structural engineering research program was funded at an annual level of $80,000, and about half of that went to paint testing. During the past 10 yr we have been able to expand the program to the current FY 76 funding level of about $300,000.

Current research is assessing the effects of seismic and static forces and weathering on dams, navigation locks, and other types of hydraulic structures; under this research more suitable design criteria are being developed.

Past research has included such major projects as (a) shear strength evaluation of weak rock foundations, (b) model studies of mass concrete structures, (c) a cellular cofferdam investigation, (d) reinforced concrete box conduit investigation, (e) tunnel support research, (f) pile test analyses, (g) exposure testing of reinforced and prestressed concrete, (h) waterstop investigation, and (i) paint research, including development of painting techniques and new formulations.

Our greatest research effort over the last several years has been in the field of earthquake engineering. In 1969, by contract with the University of California at Berkeley, we instituted a study covering a wide range of problems associated with the earthquake behavior of concrete dams and intake towers. This study has included field testing as well as developing analytical procedures. Pine Flat Dam, a 400-ft-high concrete gravity structure, near Fresno, California, was subjected to forced vibration tests, as was the 190-ft-high intake tower at Silverwood Lake near San Bernardino, California. Analytical studies were made to improve computer techniques and to evaluate interaction effects between dam, reservoir, and foundation. Phases of these investigations have been periodically reported in reports of the Earthquake Engineering Research Center. The final report, which will contain seismic design recommendations for concrete dams, will not be completed before next year. A report on earthquake resistant design of intake towers was recently completed and was published in the July Journal of the ASCE Structural Division.

Another concrete dam seismic research program has been performed at WES. Forced vibration tests and analyses of two 1- to 24-scale models of North Fork Dam have been done principally to develop a better understanding of the significant parameters influencing dynamic performance so that seismic design procedures can be improved. North Fork Dam is a 155-ft-high concrete arch dam in California which will be inundated by the reservoir of the new Auburn Dam upon its completion. The prototype structure was also subjected to forced vibration testing and the results compared with those of the model tests. The model results and finite element calculations accurately reproduced the behavior of the full-scale dam.

With respect to the future, I see a continuation of our earthquake engineering program. One possible element of this program is the future testing of the North Fork Dam with the use of underground explosives to induce ground motions. This project would not be performed until Auburn Dam was ready to store water, probably not until 1980.

We also see a need for future additional research in the area of mass concrete, cellular sheet pile structures, structural foundations, underground construction, and corrosion control. To these subjects will be added the research needs dictated by possible new roles and new responsibilities of the Corps, such as might fall out from the Urban Studies or other new programs.

I hope that my presentation has given you an insight to developments in the field of structural engineering in the Corps, at least in the areas of training, technical guidance, and research. Should you have any suggestions or comments pertaining to these programs, I would be happy to receive them, either orally sometime today or tomorrow or by writing directly to me. Thank you for your attention.

COMPUTER SUPPORT FOR ENGINEERS

by

COL Patrick W. Marks*

Introduction

It has been the Corps policy to support identified and justified computer requirements for all the users. Unfortunately, the Corps structural engineering application systems, management information systems, such as the North Pacific Division's (NPD's) Columbia River Operational Hydrometeorological Management System (CROHMS), Military Construction Directorate's Automated Military Construction Progress Reporting System (AMPRS), Fort Worth District's Management Information Decision Analysis System (MIDAS), Civil Works Directorate's Management Information System (CWIS), Facility Engineering Directorate's Integrated Facility System (IFS), and the Corps of Engineers Management Information System (COEMIS) have had better identification and visibility than the structural engineering applications systems. Or, at least that might be the way you see the results because of available in-house computer support for you.

I hope this presentation may give you a better understanding of the Office, Chief of Engineers (OCE's), concern for engineering support and how your support is planned for the short-, mid-, and long-range time frames.

Hardware Procurement

Recent hardware considerations have included the low cost interactive graphics terminals discussed by the Waterways Experiment Station (WES) and displayed by others to provide a capability to produce output in your language. Both WES and NPD have been active in this field for the past 3 yr, and we are now beginning to make this available to other Corps offices such as the Lower Mississippi Valley Division (LMVD),

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* Chief, EIDSO, OCE.

Southwestern Division (SWD), and New England Division (NED).

Also available to most districts, some divisions, and most of the laboratories are high-speed remote job entry (RJE) terminals to allow access to IBM 360/370, Univac 1108, CDC 6600/7600, and Honeywell G-437, 635, and 6000 series. The high-speed RJE's are used primarily to support the S&E work load. In addition, we have the time-sharing teletype terminals such as the ASR 33's, 35's, and 38's, and the silent 700's. The terminal operates at 10 to 30 characters per second and thus provides the engineer/scientist a convenient problem solving capability.

The WES G-635 computer system is being augmented by additional disc storage, magnetic tape units, and memory and communications equipment to upgrade it to a balanced system to take advantage of the CPU capacity that has always existed and to increase throughput of the system. This equipment will be installed in January 1976.

Software Support

OCE/ECPL (Engineer Computer Programs Library) located at WES consists of approximately 110 scientific and engineering computer programs. There are 41 Category A programs which are approved by OCE Program Review Monitors; 65 Category B programs which are approved at the division level; and 3 Category C programs which are approved at the district level, or acquired from some outside source. These programs, including program documentation, are available through the WES library.

Comments being made at this conference indicate that we have failed to adequately communicate to you the purpose of the library and to adequately entice you to pull those old standby programs out of your desk drawers and make them available to the library. There is no doubt that OCE is going to have to put more effort in this area and I am sure the proceedings of this conference will greatly help us. Frankly, the Corps cannot afford the luxury of reinventing the wheel in program development because of inadequate documentation (both user and program) of potentially good programs which are not readily available to all the Corps family. In this area, my personal opinion is that the use of the

OCE monitors will be required whether or not they do the review personally or have someone like WES to do it for them. Programmers developing new programs must consider the requirements of the other divisions and districts unless they are solving unique local problems. I know that the Missouri River Division (MRD) is working on a model for OCE which I understand to be a candidate for Corps-wide use; it will consider other division/district requirements. Let me say, in the case of S&E programs, that we still must allow the engineer to use his professional judgment. Hence, I personally think we should identify Category A programs as those having preferred Corps-wide usage rather than mandatory usage.

INFOCORP

The primary objective of INFOCORP is to advance the exchange of information concerning the most effective use of computer systems throughout the Corps of Engineers. A further objective is to minimize the duplication of effort among Corps members in the development and analysis of hardware and software systems for general use.

Research Support

R&D money has been provided for a variety of research projects under two primary concepts: (a) IDEA (Improve Data Effectiveness and Availability) and (b) ISRAD (Integrated Software Research and Development). The IDEA project was initially established in 1970 with the objective of developing more effective techniques for computer-assisted design of information systems, simulation, and modeling in support of military information systems and components; development of techniques for general improvement of data handling operations within the Army; and to support projects in computer sciences which are not supportable with mission related funding. In July 1974, the Computer Systems Command was assigned the responsibility for development of an ISRAD program in computer software techniques. In August 1975, the IDEA project was incorporated under ISRAD. Some of the work performed and future projects under IDEA/ISRAD include:

a. Survey of state of the art in computer graphics.

b. Formation of a consultant task group with representatives from OCE, WES, Army Materiel Command (AMC), various universities, and the Naval Civil Engineering Laboratories.

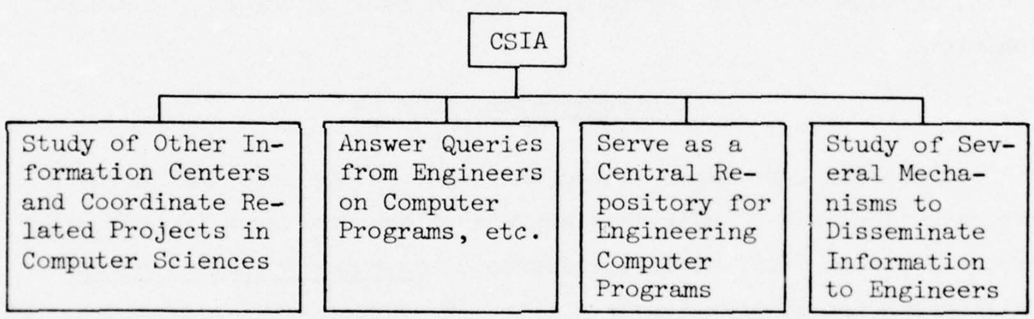
c. Development of an Interactive Graphics Package for Finite Element Analysis.

d. Examination of the applicability of computer graphics to the fields of architecture and engineering in military construction (AEADS).

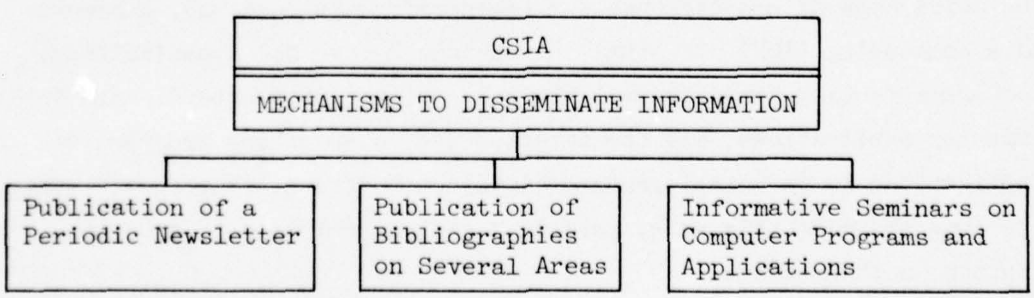
e. Establishment of a computer sciences information activity (CSIA).

Support of CSIA project

The principal objective of the CSIA project is to study the feasibility of the formation of a Computer Sciences Information Center for the Corps of Engineers and, subsequently, to extend the concept to the Department of the Army and the Department of Defense.



Several information centers, i.e., Soil Mechanics, Concrete, Hydraulics, and Pavements are funded by Army RDT&E. They have proved both successful and useful. However, these information centers serve specialized fields in civil engineering. On the other hand, CSIA must service computer-oriented engineers whose disciplines are widely different.



The Center must perform functions of dissemination, analysis of data, writing of state-of-the-art reports on application areas, etc; in other words, a means of technology transfer.

Support of Engineering
Computer Notes (ECN)

As part of the CSIA project, WES prepares a technical note called the "Engineering Computer Notes" to test dissemination of information to engineers. The first issue of ECN was published in March 1975. Hopefully, the ECN will be used by the Corps of Engineers as a source of information about computer related (both hardware/software and applications) activities in the Corps, announcement of courses and seminars in engineering computer technology, and as a forum for exchanging information and ideas between the engineers in the various Corps offices. In short, it aims toward being an information service for the inquiring engineer.

Dissemination Efforts

There has been ample stated this week on the need for improved dissemination, and I think this conference has done much to help close the gap. Another effort is the course on Computer Applications and Utilization for Engineering Executives (6 courses - 210 attendees). The objective of this course is to provide engineering executives and supervisors with information concerning the use of computers for engineering applications in the Corps of Engineers. The course focuses on providing the executive with the necessary background to properly evaluate the use of computers in engineering applications in order to improve management of engineering studies and other technical studies. The course covers the philosophy of computer use for engineering applications, automatic data processing (ADP) planning, the administrative and organizational factors affecting computer use, the value of training subordinates in computer applications, and the importance of documenting programs and applications in technical areas of interest to the participants. From the comments made this week, several divisions may need to give more support to this effort.

The Engineer Computer Concepts and Applications Group (ECCAG) (16 members; 4 OCE, 12 field) was established in September 1968 to meet pressing engineering and scientific computer requirements in the Corps of Engineers. The members are a field-oriented coordination body of selected engineers and computer specialists. The Group, through its Chairman, recommends actions and functions for my coordination. The objectives of ECCAG are:

a. Analyze Corps-wide requirements for effective use of the computer as an engineering tool.

b. Formulate guidance for, and prescribe as desirable and practical, standardization of computer hardware and software for Corps-wide application to engineering applications, particularly with respect to centralized computer systems and uniform or compatible computer languages and programs.

c. Familarize the engineer with existing programs which apply specific design methods to a problem.

Contractual Support

Some of the Corps ADP support, particularly S&E applications, is obtained through contractual support services for commercial sources and other Government agencies. AR 18-1 and ER 18-1-2 establish the provisions which govern these contractual services to include the levels of authority to approve requirements for such support. At the present time, the district has the authority to approve contractual requirements up to $10K. Division and lab support have the authority to approve requirements for up to $35K of contractual support, and OCE can approve requirements for services which do not exceed $200K. Requirements which will cost more than $200K to provide must be approved by ASA(F&M). Of course, MISD recommends to the Secretary on requests for approval.

The Corps obtains ADP contractual support from a variety of sources, such as CDC's INFONET, Lawrence Berkeley Laboratories, National Bureau of Standards, NASA, McDonald-Douglas Automation (MCAUTO), HISI's Data Network, Cybernet, General Services Administration, BCS, WES, and various universities.

Planning

Planning for the future ADP environment to support Corps requirements is a high priority task at OCE and in the field.

Two parallel and mutually supportive efforts are on-going at OCE in this arena of ADP planning. The first of these is the OCE Five-Year ADP Program Plan which is the midrange plan of where we are going in the ADP support of Corps activities.

This plan now projects the next Corps main-frame configuration as being on a regional basis. Two Corps Districts, Fort Worth and Jacksonville, have been selected to conduct a study of minicomputer capability to accomplish stand-alone S&E and/or business processing while simultaneously communicating with large main frames. The study will develop data necessary to support or refute the feasibility of this approach. If feasible, specifications for a competitive buy will be prepared.

The OCE Mission Systems Master Plan (MSMP) has been consolidated and distributed to the Corps divisions and labs to obtain their comments and identification of their ADP requirements for the planning period. In its final form, the MSMP will augment the OCE Five-Year ADP Program Plan for identification of Corps ADP requirements out to 1986. EIDSO will use this MSMP as the primary tool in preparing the GFSR for the Corps-wide main-frame change during the 1978-1980 period. MSMP will not cover dedicated systems.

The primary planning effort at divisions/districts and laboratories will be the preparation of input to the MSMP. This effort is vitally important because how well we prepare our system description and requirements will determine how satisfied the users will be in the 1980's.

A final important planning activity is one concerned with data communications. The growing importance of teleprocessing associated with projected regionalization makes it imperative that we fully investigate and exploit the capabilities in this field. WES has recently completed a concept study for a recommended Corps data communications network. This study is being analyzed and evaluated with respect to

the other plans of the Corps ADP program.

About a year ago, we said we would never do 100% of our engineering or business in-house. It would not be economical to do some "one-time" jobs in-house. I confess that up to about 7 months ago, I thought that in excess of 75% would be in-house. I am almost convinced, and I would like to get your reaction, that it might be wise to leave up to half of the S&E work load on contract. The primary reason is that you would have access to technology as it develops. The approval cycles are not easy, and you cannot always envision the state of the art, if you bring all your work load back in-house and take the benefits, then when new technology develops you have a more difficult time justifying going on contract. Leaving a portion on contract will give you more flexibility and may even give you better support.

This situation may represent part of the intangible returns from our decision in April 1974 to move practically all of the S&E work load out-of-house. The figure of 50% remaining on contract for the future may be too high. I do not have a magical figure and would be interested in your reaction, within the next 3 to 4 months, as to what percentage should remain out-of-house. Feedback can either be through your ADP Coordinator or through your functional personnel to OCE functional personnel and from OCE functional personnel to me.

When I say "out-of-house," I don't mean all commercial contracts; other Federal agencies as well as other DOD computers are included in out-of-house contracts.

Certainly I subscribe to the theory that you must retain some in-house expertise on ADP, much the same as the engineers must retain in-house expertise in order to properly check Architect-Engineer (A-E) contracts.

In summary, it takes you, the user, the ADP centers of your districts and divisions, the OCE functional personnel, and EIDSO working as a team if we ever hope to efficiently satisfy the user's needs in computer applications. The team working is more important than the decision of how we satisfy the user; either all in-house, partly in-house, and partly contract, or by contract alone.

THE ROLE OF COMPUTERS IN CIVIL WORKS DESIGN

by

Charles F. Corns*

Good morning. Today I am back to address more directly the subject of this conference. Yesterday I spoke about the training of structural engineers, the responsibility of OCE for issuing technical guidance to field offices, and the structural engineering research program. You probably recognize the major role being played by electronic computers in all three of these areas.

Recent structural engineering research has included efforts to develop stress analysis techniques for dam structures which can be solved with the computer. This has been a particularly prominent part of our earthquake engineering research. A great portion of current engineering research is being performed with computers. Computer models are replacing or at least supplementing physical models; we will probably see much more of this in future years.

Also, Corps of Engineers technical guidance and requirements for stress analyses now recognize capabilities dependent upon use of the computer. Dynamic response analyses of the type that we believe will be widely used in the near future would be impossible without the aid of the computer. The finite element method of stress analysis became a practical tool only after development of modern high-speed digital computers with their tremendous computational capacity.

The first use of the finite element method in connection with a Corps Civil Works project occurred around 1961-1962 in the Southwestern Division. This was the investigation of cracking at Norfork Dam done by the University of California at Berkeley for the Little Rock District. Since that time finite element analysis has been widely used throughout the Corps not only in connection with problems at existing projects, such as the Norfork Dam, and the associated design of remedial measures,

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but also in the design of new structures.

At Dworshak Dam, the second highest concrete dam in the United States, computer-aided analyses were made to determine internal and foundation stresses due to external and dead loads. Several unprecedented studies were also made possible by the computer. These included temperature stress studies using a program allowing for incremental construction, a time-dependent elastic modulus, biaxial creep, and a variety of cooling procedures. Specification requirements for concrete placement, including precooling and postcooling provisions, were developed from these studies.

During the foundation excavation for Dworshak Dam, a number of weathered zones and shear seams were discovered. These required an immediate evaluation. This was done and remedial measures were developed, without unduly delaying the contractor, through use of a finite element computer analysis.

Dworshak is only one example but it illustrates what is now possible. Another application of computer-aided design that illustrates the benefits and the indispensability of the computer is the design of pile foundations for navigation dams and locks. The projects on the lower Arkansas River are pile-founded and the involved scope of foundation studies could not have been realized without the capability of the computer. You can imagine the insurmountable task of developing without a computer an optimum pile layout for a lock wall which will be subjected to varying hydraulic loads during normal operations, the unwatered maintenance condition, the construction condition, and, possibly earthquake loadings. There are other similar situations, of course, and you will be talking about these during this week.

The design studies for the proposed replacement structure for Lock and Dam No. 26, which will be pile-supported, were made with the aid of the computer. You will probably learn more about the experience at Lock and Dam No. 26 from representatives of the St. Louis District attending this conference.

With respect to training, computers will be predominant whether the training concerns learning to use the finite element method of

stress analysis, evaluating the dynamic response of structures, or instructing personnel on available programs. This conference, in a sense, is a training meeting; we expect that the exchange of information on computer programs and concepts, which is the principal purpose of the conference, will be instructional and beneficial to all attendees.

One of the major goals for Civil Works is to eliminate the losers and push the winners. This goal could very well be the theme for this conference; during this week we'll have an opportunity of seeing field office presentations of structural programs and engineering methods that are proven winners.

I am sure that one thing which will come out in this conference is an appreciation of the commonality of many of our structural problems.

I have had the opportunity of going over your preconference questionnaires and one message came through loud and clear. Many engineers are not being kept up-to-date or properly informed on developments in programming and computer-aided design.

The major problems are, first, a need for better information on what programs are available; second, a need for improving the documentation of the programs you are able to locate; and third, where to get help when you have trouble using a computer-aided design program.

Your responses have confirmed our belief that this conference is not only necessary but long overdue.

During the presentations and speciality sessions you will have the unique opportunity of not only showing how you are approaching your structural problems but also learning how other offices are solving similar problems.

We are hopeful that your experiences here will encourage you to take a second look at the efficiency of your own problem solutions. The success of this conference can ultimately be measured only by whether you apply what you learn here.

In the early days of computer-aided design, the engineer was not only faced with finding out what a computer could do; he also had to learn how to program it and then try and convince his somewhat

skeptical fellow workers and superiors that the "Black Box" had actually produced something useful and correct. Today's engineering student is getting a pretty well rounded education in computers during his college years, as attested by the fact that over 95 percent of the Engineering Curriculums require computer courses.

The engineer today is not faced with the same programming problems of his predecessors, as many of the "bread and butter" programs have been written. Within the Corps of Engineers alone we have more than four thousand (4000) scientific and engineering programs. We are fortunate in this respect, because the cost of writing new software is increasing at an alarming rate. We can no longer afford to write new software until we're sure that one doesn't already exist that will do our job. And so we come back to one of the principal difficulties, that of locating programs in which you can have confidence and which will still do a cost effective job.

The emphasis in Civil Works is not on teaching an engineer to program, but rather on applications and techniques that have proven themselves. In addition we're looking at ways we can improve, upgrade, and make available the many good programs we now have.

This does not, however, mean that we as engineers can blindly accept results just because our problem has been massaged by a computer or the program "approved by higher authority." In fact, as computer programs become more sophisticated, the engineer has to match this sophistication in his analysis of the computer output if he is to evaluate the results properly. Only through sound engineering judgment can we separate the wheat from the chaff. Unfortunately computers are still producing a lot of chaff! Because of this, there is an ever-increasing need for the engineer to make a thorough and thoughtful analysis. He cannot abandon basic engineering fundamentals and logic because he is using a computer.

Let me cite an example of this which occurred some 7 or 8 yr ago. Results of a finite element analysis for a mass concrete structure submitted by a district office appeared questionable on the basis of the judgment of the reviewer. When the analysis was returned to the

district for checking and reanalysis, district personnel became very indignant and replied that the results had to be right because they represented a computer output. It was necessary for us to cut analytically a section of the structure in question, and sum up the plotted stresses across the section to obtain the magnitudes of forces, which we then showed did not satisfy the principles of static equilibrium, before the district would correct the program and perform a new analysis.

The computer is not an engineering tool to compensate for experience and sound judgment. It is to augment competency and facilitate the engineering calculations which enable us to now solve problems more efficiently and more accurately. With the computer it is practicable to assess the impact of all parameters of input to a problem, helping us understand the significance of any deviation from actual conditions.

In the face of increasing software costs and in order to make the best use of programs that already exist, Civil Works is actively supporting and encouraging training and workshops on specific engineering applications. We've given enthusiastic support to this conference.

During FY 76, Civil Works is sponsoring 33 training courses. At least half of these courses include applications using computer programming. In addition, Civil Works is continuing an active program on the development of computer applications. This work is being done by the Waterways Experiment Station (WES) in conjunction with several district offices and is designed to put the best techniques and application programs in the hands of the practicing engineer.

Some of the products from the Civil Works development program will be presented later this week during the specialty sessions.

One of the important aspects of our engineering work, whether it's done at the district, division, or OCE level, is the review of design--both the in-house design and that which we contract to A&D firms. Although Civil Works has made some inroads in improving design review techniques, only a small part of the review is now computer assisted. If we are to use the computer effectively, this is one area where a great deal of work remains to be done.

Throughout this conference the one consistent theme is to let

you know what programs are available and to whom you can turn for help in a particular application. I'd like to highlight three avenues that are open to you.

The first concerns the Engineering Computer Program Library that's maintained at WES. There are over 100 programs in this library that have Corps-wide application. About 30 percent of these programs deal with structural applications. If you are not familiar with this library, I recommend you contact Rich Malm or Dick Delyea during this conference or your Automatic Data Processing coordinator when you return home. Based on the proceedings of this conference, we expect to improve materially the quality and scope of this library in the structures and soil-structure interaction areas.

Second, we have a Computation and Analysis Section within Civil Works whose mission is to assist the field elements with engineering computer applications. Their goal is to devote 90 percent of their time to field related problems.

The third source is to make use of the engineer computer program review monitors for various disciplines within the Engineering Division of Civil Works. ETL 1110-1-50, issued in July 1971, informed of points of contact for information and assistance concerning engineering computer applications. Review monitors for each engineering specialty were listed and field elements were invited to contact these monitors informally for advice concerning location and application of engineering computer programs. I urge you to make use of these monitors when and if you are unable to obtain help locally.

While the principal objective of this conference is to exchange information on computer programs and concepts, I hope it also generates some new ideas and suggestions on how we in OCE might better carry out our role of promoting the proficient use of computers for solving engineering problems. In this regard, I look forward to the summary of this conference.

I wish you all a very constructive and interesting meeting this week. Your individual contributions will be most welcome and will be very much appreciated. I thank you for your attention.

COMPUTER-AIDED BRIDGE DESIGN

by

William D. Ashton*

The Rock Island District has been active in the computer-aided analysis and design of structures. The structural section uses the computer in the design of a wide variety of structural applications, from RCP installations to the stability evaluation of major lock-wall monoliths. Highlighting our design accomplishments are the designs for over 10,000 lin ft of highway and railroad bridge relocations representing approximately $15 million of civil works since 1970.

The computer-aided bridge design systems to be discussed evolved from the requirement to design numerous 3-span county road bridges included as relocation items in Red Rock and Saylorville Reservoirs. In 1966, the design analysis for one 3-span structure required 6 engineer months plus about 2 engineer months of checking at a cost of around $12,000. The design system that was developed permitted designing and producing construction drawings for this 3-span bridge in less than 3 engineer weeks, a savings of over $10,000 per structure.

The system started with a series of time-saver computer programs, crude iterative procedures that did the highly repetitive computations. These time-savers have now evolved into conversationally oriented analysis programs which permitted the efficient analysis of this 442-ft, 3-span plate girder for moment and shears at the 10th span points to be produced in less than 30 min. Conversationally oriented programs have also been developed for the analysis of the composite and noncomposite steel girders.

The Rock Island District has a relatively small structural section. The section has 4 structural engineers, 4 engineering technicians, and 1 supervisory structural engineer. This group prides itself in turning out many complex analyses and detailed construction drawings. The engineers have developed sufficient computer capability to permit the

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* Chief, Structural Section, Rock Island District.

majority of design work to be performed "in-house." "In-house" design results in an ever-increasing capability to create effective designs and creates a satisfying professional environment that retains energetic young engineers.

The section endorses computer-aided design. The computer capability we have developed permits more engineering to be focused on the vital decision-making aspects of design and fewer hours to be consumed laboring away at repetitive computation. The computer capability consists of remote terminals which provide service to the Waterways Experiment Station (WES) 635, the Computer Science Corporation Univac 1108, and a Honeywell 6000 computer in Minneapolis. The basic terminal is this Silent 700. Recently, a Tektronix 4012 was obtained to aid in understanding, developing, and using engineering graphics.

The first bridge we will discuss is the Milwaukee Road's new bridge across the Des Moines River Valley; soon to become Saylorville Lake. This $5.3 million structure was designed by the Rock Island District using computer-aided design techniques for the analysis of the telescopic reinforced concrete piers and the welded deck plate girder spans. An aerial view of the completed bridge is shown in Figure 1.

In developing a successful computer-aided design system it is necessary to avoid designing an engineering tool that will be awkward and will keep engineers from using the system because it is too sophisticated for them. The programs to be discussed here have been accepted by designers and consequently have provided the components of computer-aided design that resulted in a successful design system. This group of engineers emphasizes the fact that many people with many abilities are required to design and construct any given bridge, even with the help of a computer.

The Milwaukee Road bridge was designed for a Cooper E-80 Diesel Load. The analysis for the moving Cooper load series or wheel train was accomplished using the conversationally oriented program, WTRAIN, available on the 1108, the WES CORPS systems, and numerous batch systems.

The 106.5-ft welded A588 girder is 10 ft deep, has a 3/4-in. web plate, and has central flange plates 20 in. by 2-1/2 in. by 75 ft 0 in.

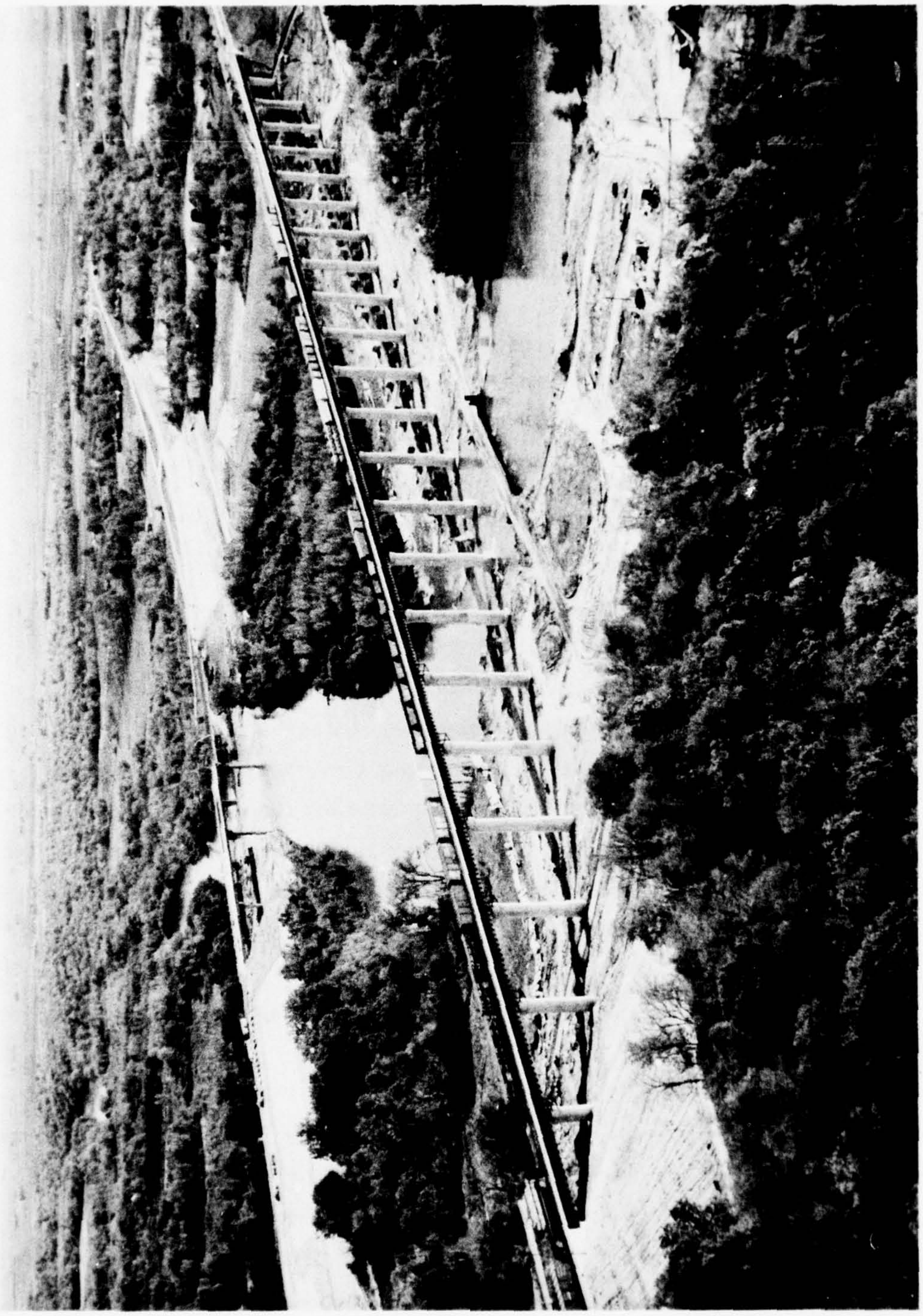

Figure 1. Aerial view of Milwaukee Railroad bridge

Girder delivery is shown in Figure 2. The girders were analyzed at the 20th span points for determining sections and the analysis was repeated at each stiffener location when analyzing the cross frames. They were manually analyzed for deflection, accounting for the variable moment of inertia using Newmark's techniques. Programs are available to perform this deflection analysis; however, the manual application of Newmark is rapid and approval was easier to obtain.

Using direct questions, the conversational format requests the span length, the analysis points, and a load code corresponding to the wheel series. The program will handle any wheel series containing up to 20 concentrated loads followed by a uniform load.

A typical summary output sheet provides maximum values of moment and shear at each requested analysis point. Here the Milwaukee girder live load analysis is summarized at each 20th span point. Developing comparable data for the envelopes of maximum moment would require many engineer hours of tedious manual computations.

If requested, the program will provide the value of moment and shear for each concentrated load at the peak of each of the influence lines. The program software actually performs a maximum routine and eventually outputs the maximum values at each point when the summary alone is requested.

Each program has sufficient documentation to enable the user to apply the program correctly to the particular application. The user's guide contains a verification which was made by the author prior to the program's initial use.

There are 22 reinforced concrete piers varying in height from 42 to 136 ft. The piers are all founded on H-piles driven to weathered limestone and shale. The piers were analyzed for the dry reservoir, the conservation pool, a level corresponding to what we believe produced the most likely severe ice condition, and of course full flood pool (this is approximately at the intermediate step between the upper 60-ft and lower 40-ft pours).

The analysis actually starts at the top. The engineer, using his experience and ingenuity, determines the correct size for economics.

Figure 2. Delivery of girders to Milwaukee Railroad

Much engineering insight into construction methods and costs must be used in these decisions. These many variables make computer-aided design attractive. The computer does the tedious tasks and makes available engineering time to evaluate the impact of a chosen set of alternatives. In the case of these piers, such design decisions resulted in a value engineering credit of $1.5 million for correct revision of pier geometry consistent with modern construction practice. It is obvious the designer can never be replaced by a computer, but he needs the computer tools to aid in creating effective designs.

The axial loads and biaxial moments at a given plane from the top are input into a program called General Flexure, which originated at Seattle District. The program requires the coordinates to describe the concrete boundary and the coordinates of the resteel.

A graphical representation of the analysis is provided. The neutral axis is provided, the concrete stresses at each boundary coordinate is output, and the steel stress in each rebar is provided.

Sections through all the pier shafts were identical at each incremental distance below the pier top. The required variation in pier heights was achieved by changing the bottom shaft section by form panel length increments and varying excavation depths. Flat surfaces of each pier were formed using 6-ft plate girder forms. The telescoping effect was achieved by using 8- and 10-ft-diam half-round panels.

The General Flexure program is coded for the lower section. New concrete boundary coordinates had to be described and coordinates of the outer concentric row of No. 14 bars had to be added to the previous rebar data.

The computer can efficiently handle the analysis. However, the designer must be capable of visualizing the construction procedures, such as the Cadweld splices which make the inner rings of bars continuous lines of reinforcing from the pier top to the footing.

The analysis is continued with the engineer providing the axial loads and biaxial moments as the stresses are checked in increments proceeding toward the base. This is loading of the 124-ft pier used to provide loads for the pile foundation analysis.

A time-saver type program took the loads and grouped them into the engineer's specified loading combinations. Our engineers are encouraged to develop individual applications. Generalized programs should be developed only when the method of solution provides the generality. It has been shown that the use of these short, simplified time-saving computer routines can be developed rapidly and provide substantial benefits, even if applicable to only one project.

Approximately 68,000 lin ft of 12HP53 piling was driven for the pile foundations. The piles were driven with a single-acting air hammer. The hammer was provided with fixed-type leads which were extended at the top and held by a pin connection at the bottom. The leads could be adjusted by cable-powered pipe struts for both forward and backward batters. The leads could be raised and lowered into the foundation excavations.

The pile driving operation was efficient. The contractor drove over 2100 lin ft of piling, approximately 60 pieces, on several occasions in a 9-hr day. Higher productivity was hindered because of the down time required to position piling within the excavation prior to pulling individual pieces into the hammer leads.

A pile test program was used to provide construction control for the H-bearing pile foundations. The test loads were applied to the test pile by means of a hydraulic jack reacting against the loaded test frame. The contractor was responsible for providing the jack and applying the load as directed by the design engineers. The field data were plotted on a Calcomp plotter.

Construction engineering can use both computational and interactive graphics applications. The remote terminal can certainly benefit the construction field office operation.

The unbattered pier shaft design permitted use of standard dimension modular steel forms throughout. Scaffolds with walkways around the entire pier shaft facilitated all phases of pier construction and minimized the hazard to workers. The use of standard modular forms coupled with the repetitive geometry resulted in an average bid price for structural concrete of $60 per cubic yard.

The superstructure consists of twenty-three 106.5-ft welded deck girder spans fabricated from ASTM A588 steel. The girders were fabricated using over 2000 tons of steel plate. A work train positioned the train load of girders on the existing viaduct. The individual girders, each weighing 72,000 lb, were lowered to the ground using the American 9260 with 190 ft of boom. The fabricator used computer software to provide cost and inventory controls.

The girder spans were assembled on the ground. The A325 high-strength bolts used in the lateral system were torqued to specifications. The assembled units were then lifted to the pier tops. The American 9260 was coupled with a Manitowac 4000 to perform this precision lift of 164,000 lb. The deck was a precast concrete ballast trough. A close-up of the completed bridge is shown in Figure 3.

Computer-aided design provided us the time to become deeply involved in the removal of the old structure with modern precision explosive techniques. At the conclusion of this presentation, you will be shown a film produced by the District's design branch depicting the demolition of this massive viaduct.

In all phases of the design and construction, engineering experience complemented with computer-aided design programs produced a superior product in greatly reduced time and consequently realized lower project costs.

The next structure is the S&V highway bridge designed by the Rock Island District in February, March, and April 1970 using computer-aided analysis techniques.

The new bridge shown in Figure 4 is 4934 ft long and 30 ft wide. The bridge is about 80 ft above the Des Moines River Valley. The cost of the 2.2-mile-long, high-level crossing of Saylorville Lake was $5.8 million.

Computer programs for generating influence coefficients for continuous spans had been written at Rock Island during the late 1960's. Programs were also written for the evaluation of these influence lines for the AASHTO loadings. This made it convenient to study continuous bridge superstructures, since moments and shears at 10th span points

Figure 3. Milwaukee Railroad bridge

Figure 4. S&V bridge

could be computer calculated in approximately 30 min of machine time. These programs have been combined into a new conversational-oriented program called INFORD.

The General Flexure programs discussed earlier during the Milwaukee Railroad bridge discussion were available for the analysis of these reinforced concrete sections subject to direct stress and biaxial bending. A program was written to provide the stability analysis of the piers for the group loadings designated in AASHTO. Thus, the design moments and the magnitude and location of resultant forces coupled with the General Flexure capability provide a computer-aided design procedure which resulted in an efficient and rapid analysis of the reinforced concrete pier shafts for the many required load cases.

The problem, therefore, was not one of engineering analysis, but one of engineering an economical, attractive design consistent with modern construction practice. I must emphasize that a complete understanding of the analysis provided by the computer software, which would have required approximately 2 yr without the computer, is essential in establishing sensible and economical layouts.

An experienced structural engineer can sketch the structure, satisfying the specifications' empirical rules prior to analysis, to insure that fabrication details are economical. Computer-aided design, with an engineer using a remote terminal on his desk, permits rapid evaluation of his ideas and can greatly enhance his ingenuity and make maximum use of his knowledge.

The ability to readily evaluate a given set of alternatives reduced the 180 required girder pieces into three basic types. This simplified fabrication of 7.8 million lb of A-36 structural steel so that it was fabricated and erected for 26.7 cents per pound or a $0.75 million savings, a direct result of permitting experience to intervene at appropriate times and make logical decisions during the computer analysis.

The pile foundations required 9 miles of 10-in. H-pile. Timesaver programs were written to provide the pile loads corresponding to

each group loading combination specified in AASHTO and outputted by the pier stability program.

The design incorporated identical pier geometry on 24 piers so that formwork could be reused throughout the job. The unbattered pier shafts permitted use of standard dimension modular steel forms available in the construction industry. In addition, the repetitive geometry simplifies the input into the General Flexure program and reduces required design time.

The contractor also recognized the repetitive design and conceived a tilt-up pier construction procedure, illustrated in Figure 5. The procedure was, basically, to assemble the formwork and pretie the reinforcing in the horizontal position on the ground. Next, the pretied cage was placed in the form and the form with rebar was tilted and placed on the footing forms. The footing was filled with concrete and the following day the shaft was filled with concrete. The tilt-up procedure resulted in low concrete and rebar prices. The winning bid was $65 per cubic yard. The tilt-up procedure reflected an 80% reduction in labor cost and resulted in timely completion of the structure.

The analysis of a 5-span continuous plate girder is a monumental task (Figure 6). Girders are shown in place in Figure 7. The required influence line for moment at each 10th span point would require positioning a unit load at 51 locations, performing a moment distribution analysis at each location, and solving 51 free body diagrams or some 2500 identical sets of analysis just to get started. There is no better example in which to derive benefits from automated analysis.

The program's conversational format asks direct questions to obtain the span lengths and girder spacing data. Using this input, the program computes the influence coefficients for each 10th span point on the continuous girder. Then subroutines compute the required positive and negative areas under the influence line which are required for analysis of lane loadings. Other subroutines provide the ordinate values corresponding to the AASHTO H-truck wheel locations.

At one time these coefficients were plotted on the Calcomp plotter. A young engineer probably needs to see these lines to gain a feel for

Figure 5. Tilt-up pier construction - S&V bridge

Figure 6. Continuous girders on S&V bridge analyzed with computer-aided techniques

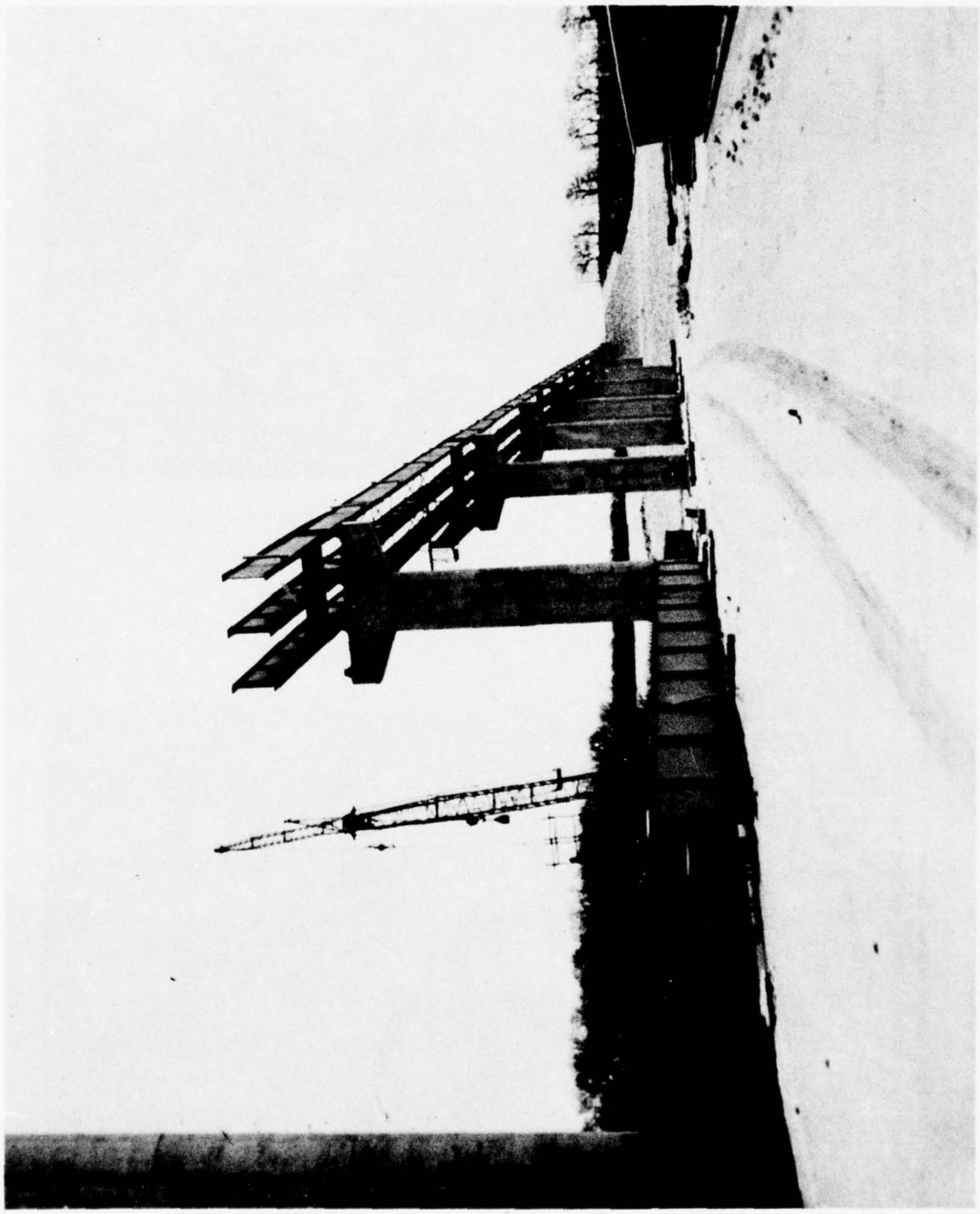

Figure 7. S&V bridge construction

the analysis. The program actually computes the areas and finds the maximum positive and negative ordinates. Interactive graphics has great possibilities in this procedure.

Having stored the areas and appropriate ordinates, the program computes the positive and negative lane and truckload moments at each of the 51 analysis points on the 5-span bridge.

These bridge moments are next distributed to the girder lines providing positive and negative values for both lane and truckload moments on the interior and exterior girder lines at each 10th span point along the girder.

These values are then increased by the specified impact according to the AASHTO rules. Again, bridge analysis is much easier to program because the specifications are universally accepted and the rules well defined.

Next, the dead load moments for the slab and girder and the dead load moments corresponding to the curb and railing and wearing surface are provided.

Finally, the total design moments for each 10th span point on the interior and exterior girders are sorted out using maximum routines and tabulated in the output.

Next, the designer must come up with a girder section which is economical to fabricate. Computer-aided design procedures permit the engineer's knowledge of fabrication, erection, available plate dimension, etc., to be entered into the software logic. This procedure results in superior designs and realizes lower project costs.

The girder sections over the piers are analyzed for negative moment as noncomposite girders. The conversational program GIRD 1 requests the top flange, web, and bottom flange dimensions, the total moment, and total shear. The output provides the neutral axis and the appropriate steel stresses.

With this computer tool the engineer can readily develop the moment resisting diagram and determine economical points of transition along the girder length.

The positive moment sections are analyzed using a conversational

program called GIRD 2. This program's input consists of the flange and web thickness, and the slab thickness. The program analyzes composite plate girders using analysis procedures outlined in design examples published in United States Steel's "Highway Structures Design Handbook."

We actually made the output format identical to the design examples in the handbook. Thus, the handbook provides a detailed narrative of the analysis procedure.

The output again provides the neutral axis for the composite girder for each required equivalent concrete section and outputs the stresses at top of steel, bottom of steel, and top of slab for various loading combinations.

Girders were brought to the site using two trucks. They were lifted to the pier tops using two American 9260's in tandem, a satisfying result made possible only through computer-aided design.

The structural section at Rock Island looks forward to the continued application of computer-aided design. We are preparing to design a lock structure for New Orleans with the analysis of the sector gates and gate bays presenting an opportunity for computer analysis. The 3-dimensional sector gate will provide a test for numerous graphics applications. We are involved in studies with Detroit on new locks for Sault Ste. Marie and these studies will require computer input and development of new techniques. In addition we will continue the daily applications of computer techniques to everyday structural problems involved in operation and construction. We look forward to working with you in the development of designs using computer techniques.

Movie: Demolition of Milwaukee Bridge.

ENGINEERING COMPUTER GRAPHICS

by

James B. Cheek, Jr.*

You see this ADP Center slide and you say, "Here it comes, another one of those computer fellows." Yes, I am a computer man and I often speak on our computer center's role in engineering. We would like you to think that our computer center has it figured out a little better than some of the rest of them did, maybe even sooner. We found that a computer center must be more than hardware, operators, and system support people. In order to make it an engineering computer center, you must have some applications support. I say that, because I will present this talk on Engineering Computer Graphics from the standpoint of being the Chief of an applications support group.

I will approach this subject from the standpoint of two old timers; one of them is me and the other one is the IBM 650 Computer that got the Corps started in the computer business. As old timers, we have seen computer hardware grow from that IBM 650 to a whole room of computer equipment at the WES. I have watched time sharing grow from one little data phone, hung in the corner of our G-400 computer room, to a complete data communication system for the user base we serve.

I was rather satisfied with it all; looking at the printers, seeing reams of paper pouring out from them, and thinking, "this is a wonderful thing." I thought that until I found out what you engineers did with the paper. Most of it went in the trash can. So we asked the users, "What's the trouble, fellows?" Why all the paper in the trash can?" The response was, "We need graphics." We, being a very responsive organization, provided computer graphics in the form of printer plots.

Later on, some fellows came by and said, "You know, this isn't really what we had in mind. We need something better than that.

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We need hard copy, pen and ink graphics."

So we acquired the now famous incremental plotter. We finally did a great deal of work on the CALCOMP, but progress was slow at first. Some thought that all you need is a plotter and immediately you would start using it productively. It wasn't that easy. We drew graphs with no data; we drew graphs with data off scale, all over the page. However, it wasn't long, in terms of the people who were doing the work, but a long time for the people who were waiting for the answers, until we got to the place where we could do some pretty cute things with our incremental plotter. For instance, we could draw pictures on the plotter; but, in the early times, our software (graphics support programs) could not tell hidden lines from visible lines. So we just drew every line on a perspective view as a dashed line. We took that down to the drafting department and let a man, who is smarter than the plotter, draw the visible lines as solid lines. Then somebody colored the drawing to give an artist's view of a new project. This typical tie of computer graphics and man was fine, except that by doing accurate, low cost graphics work, we put most of the young people in the drafting department out of work.

Most of the computer centers you use try real hard to provide engineer-oriented service. We, like them, try to anticipate your needs and get new equipment for you as it becomes cost effective and dependable. Here is one example of such efforts. We found that the work load for our incremental plotter was so great that it took three or four days to get a plot back to you.

So we decided to get a microfilm plotter which has a 35mm camera that takes pictures of the plot on the cathode ray (TV like) tube. We thought the film feature was nice, but we figured the main thing you would do was to display your plots on a storage tube device that was part of the microfilm plotter. Our "reasoning" was based on the fact that we do a lot of data reduction work at WES. We thought people would come down and look at the display to isolate the graphics they did not want. When they found one they really needed they would make a 35mm film of it, and plot it later.

We were wrong; it did not turn out that way. People were just

too busy to come running down to look at the viewscope. They wanted film output. Here we made another mistake. We decided the most important thing to the engineer was low cost, so we selected the lowest cost, single-reversal film we could find. We bought the cheapest reproducer we could get. The result was that few people used our microfilm plotting system. We finally went to a high quality, full reversal film; and a very, very expensive printing device. With those we were able to produce very fine quality, almost report quality, cathode ray tube plots.

I am sure most of you are familiar with the fact that the WES does a lot of model testing, both from the hydraulics standpoint and from the interaction between the structural elements and hydraulics. These models are terribly complicated. They are quite expensive, as many of you know, because you are the people who pay us to do this kind of work. Regarding those models, we believe the computer complements our physical model work by adding the capability for using high levels of mathematical analysis on such problems. Those methods have a potential for reducing the cost of model studies. Dr. Radhakrishnan talked to you yesterday about one such method, the finite element method.

I don't know anything about the finite element method. With that in mind you may find the following view on the finite element method at least different and perhaps informative. If you have a problem that is too complicated to solve, why not take a small piece out of it and solve for the behavior of that small piece and its interaction with its neighbors. Then you can represent the original problem with one that is made up with a bunch of little pieces. That takes care of all Dr. Radhakrishnan had to say. Now you know what the method is; let's try to use it.

One of the minor difficulties is in describing to the computer what the finite element idealization looks like. In order to do that, we have come up with a scheme (we, meaning people who got started in finite element method of analysis) whereby we numbered each element. In order to describe the element, we number each one of the corners. Then by giving the element number and the numbers of the corners we describe that element. Then we record the coordinates of each one of

the corners to locate the element in space. That doesn't seem like a terribly difficult job until you consider the fact that you must do it <u>for every element in the whole structure</u>.

Now you see the problem. How can you be sure you have correctly defined the structure? The answer is to make a plot of the structure. Thus, we wrote programs to draw the picture defined by the finite element data. Then the user decides whether the picture is correct. But that was just a partial solution. Why? Consider this illustration.

This is how we defined a structure to the computer several years ago. The first thing we did was to "let" Vicki (who used to be my secretary; now she is everybody's secretary) take numbers off the drawing while Kathy recorded them on a data form. Then our versatile Vicki went to the keypunch and prepared the data cards. Using those cards and our plot program we produced a picture. Usually the first plot did not look much like the original, but after many, many tries, we finally ended up with a valid grid.

Some people are using such edit-plot procedure for 3-dimensional problems. Take for example, the work we did with the Weapons Effects Laboratory (WEL) at WES for the New Orleans District. We were trying to make a 3-dimensional finite element model of a lock wall. I went up to WEL one day and what did I see, but a wooden model of the lock. Looking closer, I saw it was a finite element model. Somebody had scratched lines on it in an attempt to keep track of nodes and elements in such a complex 3-dimensional model. So if you think the description is difficult for 2-dimensional problems, it is really bad for 3-dimensional problems.

Getting back to computer graphics; we had a lot of equipment, but it was all located in the ADP Center. Step out the back door and you would likely find people sitting in the parking lot, waiting for their output to come back. Sometimes it took two or three days. To bring graphics to the engineer we provided the Hewlett Packard XY plotter terminal that can be used with any time-sharing system. Those devices provided a form of interactive graphics, right in the user's office.

With those terminals, we were able to prepare data for a 3-dimensional model such as this dam at North Fork. The WEL at WES did the analysis; we tried to help them get the grid ready. The basic procedure was the same as that used to prepare 2-dimensional grids. We used cross-section drawing. We had people copy numbers off of them and check them. We plotted the cross sections using the small XY plotter. Since some errors might be written over, we had to watch the section being drawn. After we got all the sections right, we put them together and plotted the composite. But when we did, all we saw was a mass of lines. Back to the programming pad. We developed procedures which would cut off slices of the whole grid. This allowed us to look at portions of the grid to isolate local errors. After months of trial and error, we finally got a fairly adequate grid of the North Fork Dam. After that project was over, I heard an engineer say he would never take on another project like that one.

That represents what we called Engineering Computer Graphics at the WES, until just a few years ago. About that time we decided to see what everyone was doing with the hard copy graphics we provided. We found most of the plots were being stuffed into somebody's trash can. We concluded that the problem of getting engineering-oriented computer graphics was more fundamental than simply writing a plot program for each new problem. We went to the Office, Chief of Engineers (OCE), and the Army Materiel Command (AMC) and asked them for money to use in finding out what was wrong in the computer graphics and to develop some capabilities to make graphics work for the engineers.

The work approved by the AMC was to develop pre- and post-processors to make the finite element method easy to use. The work for OCE was to make interactive computer graphics useful for the engineers in the field offices. We did not get much money in either case, but the money from the two projects enabled us to make a unified R&D approach to graphics.

One of the things we were sure of was that we did not know very much about graphics. So we began what we called the Road Runner Show. We went all over the country talking to engineering graphics people.

We found some interactive graphics work going on within the Corps in the North Pacific Division. They were using storage tube terminals to help manage their reservoirs. We went to the Navy's counterpart of the WES, the Navy Civil Engineering Laboratory. There, to our surprise, we found another storage tube terminal. We went to see Dr. Christiansen at the University of Utah. He is making pictures, not plots on the computer. He has developed and collected equipment and software to do continuous tone shading of both black and white and colored objects that are defined by faceted data. The use of color enables him to clearly show the different component parts of a structure, and to illustrate changes in the state (pressure, stress, strain, temperature, etc.) of a component.

While on this trip, we learned a great deal, not the least of which is the fact that there are a number of different kinds of interactive graphics display devices. Plazma panels had a high degree of promise for a while. The promise, to show great big pictures, has not come through because they are rather expensive. Raster scan tubes are the kind that look like a small television set; they are bright, they have standard characters, and some of them even show simple graphs, but not to any fine detail. The lack of detail is due to the high cost of the memory needed to provide fine detail. Maybe memory cost will go down by a factor of ten; then these devices will become quite competitive. Storage tube terminals seem to be best for the Corps' engineering users for reasons I will outline in a few minutes.

At the University of Arizona, we visited with Dr. Kamel and found he used both storage tube and refresh type terminals. He has a system, GIFTS, which analyzes structures made up of plates and shells (he subsequently put the GIFTS on the WES's G-635). His system had a number of engineer-oriented features that make it easy to use. For instance he gives a lot of useful information about the angle of the view and the coordinate axes on the plot so that you can get a good idea about how you are looking at the structure. He shows the deflected structure and gives numbers or symbols that are keyed to stress ranges. This gives you an idea of stress levels without presenting a lot of unneeded data.

He can take out just a portion of the structure and look at it, without showing the other parts.

During this time, we had just acquired a refresh graphics terminal. It had a minicomputer and an interactive display tube complete with a light pen to interact with the display. Capable as that machine is, we have not found it to be useful to the field engineer. The researchers at WES may find it useful but the field engineers probably cannot afford to spend between $70 and $200,000 for one graphics terminal.

Let us compare the refresh graphics system to the storage tube. The refresh tube allows you to point to one place on the screen and erase all or part of the drawing. It draws very, very fast, it has very high resolution, and you can get it in colors.

On the other hand, the storage tube terminal is flicker free. Flicker can be a problem since the refresh terminal redraws the picture about 30 times a second. If you try to display too much information on the screen, it will take longer than 1/30 of a second to draw it. Thus it will appear to flicker like an old-time movie because the drawings are not repeated often enough. The storage tube simply draws the picture and it remains on the screen; hence, there is no flicker. You can get a high density data on the storage tube. Finally, what I believe is the most important to the field office is the fact that a storage tube cost between $4,000 and $15,000. At the upper level of money you get a very sophisticated storage tube system for interactive computer graphics. The disadvantage is that you cannot erase a portion of the picture. If you want to change one part of the picture you have to redraw the entire picture. Storage tube terminals are rather slow, depending on the data communication rates.

We made our first move into interactive computer graphics for engineers with a small screen, storage tube terminal (Tektronix 4012), a graphics tablet, and a hard copy device. What do you do with that equipment besides display somebody else's view of Los Angeles to show that you can get a lot of data on a large screen, or show a shaded view of the star of Star Trek? What are the advantages of that equipment over the Hewlett Packard XY plotter?

It took a long time for the answer to that last question to get across to me. I think I have it and would like to pass it on to you. Using the XY plotter you can draw a picture. Then you can point at the picture it drew until your finger wears out, but the computer will never know where you are pointing. Thus you can react to the picture but you can not interact with it. With an interactive storage tube device you have two cross hairs on the screen that you can move with finger tip controls. This lets you indicate (point at) an item on the picture and have the computer recognize where you are pointing. This gives us interactive computer graphics. Your program can then do things like record the coordinates, begin a line, end a line, etc. How did we put interactive graphics to work?

We used the interactive graphics techniques to make the finite element easy to use. Our first effort was in developing procedures for automatic grid generating so as to very easily prepare a complex finite element grid. We also wanted the system to be friendly to the user, so we developed an interactive language that lets the user do the talking (commands) and the computer do the work. For example, the computer types COMMAND? We type INP for input and the computer reads the data that define the structure. We type PLT for plot and the computer produces a plot of the structure. Other commands let us modify that data in case it contains mistakes or we want to improve it. Typical commands are CNN 1 2 5 which says change the number of intermediate nodes, between nodes one and two to five. Suppose there are six stars (indicating nodes) on the left between nodes one and two. That is an error because there are five stars on the right and for this example they should be equal. That command allowed us to go into the data file and change the number of nodes. The command CAN (create an additional node) uses cross hairs. We put the cross hairs where we want the node to be. The carriage return command causes the system to generate a new node at the point indicated. That is a lot better than writing the coordinates (which are often wrong), punching them in cards, and waiting two days to get the plot back. The command ATP means add temporary points which are used to control the grid generation. Again the cross hairs position

the point. The command SAV means save the current data and PLT means draw the picture again. The new plot will show five stars on the left and the other nodes we added.

Other commands like ALS 1 8 (add a line segment between nodes 1 and 8) are used to partition the structure to cause the generator to produce the kind of grid desired. Using those commands we interactively prepared and edited the data for grid generation.

With a complete set of data, the finite element grid is generated using the command GEN. The generated grid required very little data preparation. Some finite element grids can be improved by an element smoothing procedure. We have a command which will produce a smoothed finite element grid.

Now why did we do all that subdividing? Early in the development of this system, we had to divide the structure into a collection of four-sided regions. Today, you no longer need do it that way because we have improved the grid generating procedure.

At this point, a series of slides were presented showing the current capabilities in grid generating and pointing out problems yet to be resolved.

We are testing and evaluating this system on practical problems. Early tests show it is a useful tool. In comparing cost, we experienced a 2 to 1 reduction over the manual-computer-plotter procedure. We have made technological improvement that may yield cost reductions as high as 10 to 1. In our early study we found a 7 to 1 time saving. We think we are doing something useful. These costs, as Mr. Bourgeois has pointed out, are on the "tremendously expensive G-635." If we could get a better system, we could expect even better cost reductions.

That takes care of grid generating. Our next concern was to make the output more useful. We have provided several options of post-processors to present the finite element output in engineering-oriented form, and allow the user to interact with the display process. In the vector output, we display vectors proportional to whatever you like; say flow of water in a seepage analysis. You can control the size of the vector so that you can get a more meaningful display. You can

display the values that were calculated, you can draw contours and get a magnified view (windowing) of portions of the display that are important to you.

One closing remark on grid generating. We have a good hold on many types of grid generating, but there are some areas on which we need to concentrate. One such needed capability is the ability to easily produce a horizontal subdivision of the grid to meet the special requirement for incremental construction and loading that exists in many practical layered problems.

All those things we did for the Army Materiel Command. What did we do for OCE? Well, most of you are familiar with GFRAME. You may be convinced that that is an excellent way to analyze plain frame problems. A number of cost savings have been documented showing major reductions over manual procedures. For the next few minutes I will show some of the things we have done with GFRAME in developing an interactive frame analysis program with graphics options. The whole purpose of graphics is to make the computer the engineer's friend, instead of his enemy. I will illustrate this by showing what GFRAME does, now that we have added our interactive graphics package called, STRUPUT.

You may prepare a set of data and store them in the data file. This feature lets you use low cost personnel to prepare the data. First let us look at the sign on procedure that gets you ready to use STRUPUT. The system asks you whether this is a 4010 or a 4014 terminal. Your answer lets it set the graphics language so that you can get the right kind of picture for your device. This feature is one of the device independent provisions of the Graphics Compatability System (GCS) we use (it was developed at West Point). Next it asks you to enter the name of the data file; also you can tell it which file you want to use, whether it is a new or old file, and the name of the output file. After that it is ready to run an analysis for you. It tells you to enter a "Command." From that point on you are running the computer program through the command system (instead of the program running you).

Some of the things the program can be commanded to do are: display the frame; display the loads on a frame; show the frame with its

numbered joints; define new loads; and get an output data check that gives the joint numbers, the joint fixity, the numbers of the joints that make up the ends of each member, the member's height, width, and area, the joint displacement, and rotation.

The output of the analysis is presented in a form that is engineer-oriented and highly useful to the design engineer. It includes an optional printout of the input data and the numerical results of the analysis; plots of the original frame with plots of shear diagrams, moment diagrams, or deformed shape superimposed on each member; changes of the scale of any plot; and plots of single members with diagrams of either shear moment or deformed shape superimposed.

I think we computer people are about to get to the point where computer-aided design is upon us. In the past, we did a lot of things for our analytical people but only recently have we come to the point where we can help the interactive design process, in real time with interactive computer graphics. Interactive, low-cost computer graphics has been a long time coming, but today it's here. It is ready to help you.

I guess you know that I could talk about engineering computer graphics for as long as most of you would listen, and a whole lot longer than most of you would want to listen. I leave you with a couple of thoughts. Graphics is going to eliminate this massive paper output. The final results are going to be in a form that you, the design engineer, can use effectively and therefore you will be able to more productively use your time.

SOME RECENT APPLICATIONS OF THE FINITE ELEMENT METHOD IN CORPS' WORK*

by

Dr. N. Radhakrishnan**

Introduction

The finite element method is a powerful, numerical tool to solve "real-world" problems in civil engineering. Details of the method can be obtained from a number of books published on the subject.

WES Laboratories have a wide range of experience and capability in the use of the finite element method. A few projects recently completed or being pursued using finite element techniques are presented below. Most projects described here can be referenced in the "WES Reports on the Finite Element Method" (Incl 1) listed at the end of this paper. A reference list of books on the finite element method (Incl 2) and a complete list of finite element method reports sponsored by the Corps of Engineers (Incl 3) and by other Federal agencies (Incl 4) are inclosed. All four Inclosures can be found in Appendix A. Address all inquiries on the finite element method and its applications to the chiefs of the individual laboratories mentioned in the articles.

Analysis of U-Frame Lock

The analysis is performed accounting for sequence of construction (dewatering, excavation, buildup, etc.) and nonlinear material properties. Temperature-induced stresses in the concrete can also be cosidered. A computer program developed by Clough and Duncan, University of California, and modified by the Automatic Data Processing Center (ADPC) and the Soils and Pavements Laboratory (S&PL) is used in the analysis. Locks analyzed or being analyzed include Port Allen, Old River (Clough

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* Paper compiled based on input from various Waterways Experiment Station (WES) Laboratories and other Corps offices.

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and Duncan, University of California, Berkeley), Calion (Vicksburg District, Arkansas River, Lock No. 5 (S&PL), and Columbia (S&PL)). The Columbia lock analysis was complicated due to the supporting pile foundation which required modifications to the U-frame code.

Analysis of North Fork Dam

North Fork Dam, the first concrete arch dam built by the Corps in 1939, is in North Fork on the American River near Auburn, California. It is a doubly curved arch dam, 155 ft high with a crest length of 620 ft. The dam is likely to be submerged or demolished when a new upstream dam is completed. A model of the dam was tested at WES (Weapons Effects Laboratory (WEL)) under static and dynamic loading conditions. Field testing of the actual dam was also done. Three-dimensional static and dynamic finite element analyses have been done (WEL) to predict the behavior of the dam-foundation system. The predicted behavior matches closely the model and field behavior of the dam.

Buried Cylinder Analysis

Finite element analyses to determine deformation and stress patterns in buried cylinders of varying thicknesses subjected to a number of surface loads have been done (WEL). These analyses account for soil-structure interaction behavior.

Analyses of New Orleans Inner Harbor Navigational Canal (IHNC) Lock Wall

The IHNC lock wall was constructed over 50 yr back and has been performing reasonably well. Routine design-analyses review predicted, however, that the lock section will be overstressed when dewatered. The lock is laterally supported by strut walls and is a complex three-dimensional structure. Three-dimensional finite element analyses of the lock have been completed recently (WEL) to check assumptions made in

conventional analysis and predict the behavior of the lock.

Lock and Dam 26--Three-Dimensional Pile Analysis

The effect of the flexibility of the pile cap on the results of three-dimensional group pile analyses is being studied for SLD by WES ADPC using the three-dimensional finite element program (SAP4). The project will be completed by the end of FY 75.

Analysis of Distressed Structures

The WES Concrete Laboratory is currently analyzing three old lock structures that show stability and cracking problems. The analysis is being done for the Pittsburgh District using the SAP4 finite element code. One lock is located on the Monongahela River and the other two on the Ohio River.

Slope Stability Analyses-- Tioga-Hammond Lakes Project

The Tioga-Hammond Lakes Project is situated on Crooked Creek and the Tioga River in Pennsylvania. The Tioga and Hammond reservoirs will be connected by a channel large enough to allow operation of the two reservoirs as one flood control project and utilization of storage in both valleys. An approximate two-dimensional finite element analysis of the recommended design slope to provide information on stress distribution was performed (S&PL and ADPC).

Pavement Analyses

Stress analyses for pavements loaded by wheel loads are frequently done at WES using the finite element technique (S&PL). Nonlinear material properties and layering can be taken into account in such analyses. Both two- and three-dimensional (SOLSAP) nonlinear codes have been used in the analyses.

Analysis of Deep Foundations

Finite element analyses of pile foundations considering nonlinear material behavior, and residual stresses are being done at WES (S&PL). The analyses have been used to compare results of field load tests.

Two- and Three-Dimensional Analyses of Earth Dams

Finite element programs that can analyze earth dams simulating sequence of construction have been used frequently at WES (S&PL). Programs can consider either two- or three-dimensional geometry (SOLSAP program). A three-dimensional analysis of the forces acting on the outlet works conduit at Elk Creek Dam has been performed (S&PL). The effect of fill replacement in a section of the West Point Dam has also been studied with an incremental nonlinear finite element program.

Seepage Analysis of Jamaica Bay Hurricane Barrier

The hurricane barrier in Jamaica Bay in New York is designed to protect the areas surrounding the Bay from hurricane and northeasterly storms. WES (S&PL) performed a finite element seepage analysis to predict the quantity of seepage that could be expected through and beneath the barrier during hurricane surges.

Transient Seepage Analysis

Transient finite element seepage analysis to predict the location of the phreatic surface when the water level in the Mississippi River is lowered has been performed (S&PL). A two-dimensional transient seepage code is used for this purpose. Several other analyses of sudden drawdown and steady-state conditions in earth dams have also been done using the same code.

Seepage Analysis for Lock and Dam 26

The amount of seepage that enters the first phase cofferdam in the Lock and Dam 26 project during and after excavation was determined using two- and three-dimensional finite element seepage codes developed by ADPC for the Lower Mississippi Valley Division (LMVD). Two-dimensional codes were used to get detailed information about the phreatic surface exit gradients and amount of flow for different soil configurations. The three-dimensional code was used to better approximate geometry. These codes can perform steady-state or transient analysis for confined or unconfined flow problems.

Creep Analysis

A preliminary finite element creep analysis of Atchafalaya Basin Protection Levee system was done (S&PL). The computer program used calculates both the instantaneous and creep behavior of a soil structure acted upon by incremental applied loads.

Analyses to Evaluate Laboratory and Field Tests

Finite element analyses to evaluate end-restraint effects in laboratory triaxial and plane strain tests have been made (S&PL and ADPC). Plane strain and axisymmetric nonlinear finite element codes were used for this purpose. A three-dimensional program (SOLSAP) has also been used to model field-conducted pressuremeter and plate jacking tests (S&PL).

Consolidation Analyses

Consolidation analyses using variations in the FE formulation and input parameters (i.e., linear and cubic models, time step, etc.) were performed to study conditions to achieve optimum reliability of results (S&PL).

Dynamic Analyses

Several analyses of underground structures subjected to blast loads (WEL) have been made using the finite element method. These analyses are done using dynamic, soil-structure interaction codes which can also account for nonlinear material behavior.

An analysis of the effect of varying the stress-strain and strength characteristics of the backfill around buried protective structures subject to traveling airblast loadings has recently been completed using the technique (S&PL). The report on this study is currently in preparation and it will show that the amount of compaction specified can have a major impact on the dynamic stresses in the structure and on the shock environment transmitted to its contents.

Earthquake Analyses

An analysis of the Rifle Gap earth dam in Colorado subjected to earthquake motions has been done by S&PL. Analyses of Lopez and Fort Peck Dams have also recently been completed (S&PL). Preliminary analyses for the Dickey-Lincoln school project in the New England Division have recently been initiated.

WEL is planning to analyze a concrete dam for earthquake forces. Also WEL has recently completed analyzing one span of the service bridge and the two supporting piers of the Uniontown Navigational Dam. The section of the dam which is on the Ohio River will be analyzed for earthquake motions to determine the forces developed at the service bridge supports.

Appendix A: Finite Element Method

LIST OF REPORTS SPONSORED OR PUBLISHED

by

THE CORPS OF ENGINEERS AND OTHER FEDERAL AGENCIES

and

AVAILABLE AT THE WATERWAYS EXPERIMENT STATION RESEARCH CENTER LIBRARY

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Inclosure 1

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<u>FACTS: FEDERAL AGENCIES COMPUTER TIME-SHARING SYSTEM</u>

by

Richard Delyea*

Background

Early in 1971, the Standing Committee on Computer Technology of the Federal Construction Council (FCC) began, at the request of FCC, studying the feasibility of setting up a Federal computer access system. Based on its investigation, the Committee concluded that:

<u>a</u>. The full potential of computers is not being realized by the engineering divisions of most Federal construction agencies. Although most agencies have made computer facilities available to their engineers (primarily on a time-sharing basis), computer use by agency engineers has been relatively low compared to usual practice in large, private engineering firms, and in light of the current level of computer technology development.

<u>b</u>. The principal reasons for the inefficient use of computers by Federal construction agencies are that:

(1) Most agency engineers have far too few programs of proven validity available to them; most agencies can't afford to develop new programs or even adapt and validate programs developed by others.

(2) Most programs available in the agencies are so complexly written that they can be used only by engineers who are already trained in computer use, or those who must be given detailed instructions on their use.

<u>c</u>. Solutions to these problems are readily available; they can and should be implemented through an appropriate interagency program. Specifically,

(1) The problem of too few programs at individual agencies could be solved by pooling the programs already available into a consolidated interagency program library and subsequently initiating a coordinated interagency effort to develop new programs.

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* Dick Delyea, at the time of his death, 28 October 1975, was Chief, Computation and Analysis Branch, Office, Chief of Engineers (OCE). He spoke on both FACTS and CORPS. For information on CORPS, refer to Wayne Jones' paper in Volume XII.

(2) The problem of computer programs being too difficult for the average engineer to use could be solved through use of the library system developed by the U. S. Army Corps of Engineers; this employs programs with the documentation written in.

The Committee reported these conclusions to the FCC in the spring of 1971 and, at the same time, requested and received FCC authorization to develop the type of interagency program suggested in conclusion c. above. This effort was immediately begun, and in due course, the Committee transmitted to the FCC a prospectus on "A Proposed Program for Facilitating the Use of Computers in Federal Construction Agencies."

The FCC approved the proposed program and authorized its implementation as soon as the various agencies slated for participation agreed. Such agreement has been obtained, and the program is now being implemented. This report describes that program.

Purposes of the Program

The purposes of the FCC program for facilitating the use of computers in Federal construction agencies are:

a. To make available for use by all Federal construction agencies, through remote terminals, an extensive library (to be designated FACTS*) of fully validated, easily used computer programs dealing with a wide variety of construction-related engineering problems.

b. To promote the continual expansion and refinement of the FACTS library through the coordinated, voluntary efforts of the various agencies.

Main Features of the Program

Through this program the Federal construction agencies will, in essence, pool and share their computer-program resources and coordinate their computer-program development efforts for the benefit of all.

The program will be coordinated by the FCC through its Standing

* Federal Agencies Computer Time-Sharing System.

Committee on Computer Technology. Work associated with the development, adaptation, refinement, and validation of computer programs will be carried out on a voluntary basis by participating Federal agencies. Work associated with the development of the executive program for the FACTS library (i.e., the computer program that serves as librarian) and the preparation of manuals on writing programs for the library and on using the library will be carried out by the Office, Chief of Engineers, U. S. Army Corps of Engineers (OCE). The library itself will be maintained by the Atlanta Data Processing Center of the General Services Administration (GSA) and will be made available to Federal agencies through the Center's time-sharing system, RAMUS, the Random Access Multi-User System.

Costs associated with the work of the Standing Committee on Computer Technology will be covered by the general operating funds of the FCC. Costs incurred by the Atlanta Data Processing Center in maintaining the library will be covered by the standard charges for time-sharing services. Costs associated with the work of OCE will be absorbed by that agency.

Anticipated Benefits

Since many more computer programs will be stored in the FACTS library than in the library of any single agency and since these programs will be in a more usable format than are most current programs, agency engineers will be able to use computers more often and more easily than they have in the past. As a result, agency engineers should be able to perform more effectively such duties as preparing design criteria, reviewing and checking design calculations of private consulting engineers, and developing original designs.

It is believed that the increase in computer usage will be at little or no additional cost for most agencies, except for the added direct time-sharing charges. The FCC believes that the extra time-sharing charges will be more than offset by the increase in efficiency and effectiveness of agency engineers.

Roles of Organizations Participating in the Program*

a. Federal Construction Council. The FCC generally will be responsible for overall coordination of the program and specifically for ensuring that the level and nature of activity under the program are in accordance with the needs of the agencies. To carry out its responsibilities, the FCC will require periodic status reports from its Standing Committee on Computer Technology, the group responsible for coordinating the program on behalf of the FCC.

b. FCC Standing Committee on Computer Technology. The FCC Standing Committee on Computer Technology generally will be responsible for coordinating the program on behalf of the FCC and specifically for:

(1) Disseminating to participating agencies information on the program including lists of computer programs available in the FACTS library, manuals on how to prepare programs for inclusion in the library and how to use the library system, and reports on computer-program development work under way at participating agencies.

(2) Arranging workshops to instruct appropriate agency personnel in the use of and the preparation of programs for the FACTS library.

(3) Identifying areas in which computer-program development work is needed and promoting the initiation of such work at the agencies.

(4) Determining the nature and level of activity at participating agencies with regard to computer-program development and FACTS library usage.

(5) Arranging for evaluation of the technical quality of programs placed in the FACTS library.

(6) Periodically reviewing the operation of the FACTS library and, when necessary, recommending changes in its operation.

(7) Providing the FCC and participating agencies with periodic status reports on the program.

c. Office, Chief of Engineers, U. S. Army Corps of Engineers. OCE will be responsible for developing the executive program that controls the FACTS library (i.e., acts as librarian). OCE also will be responsible for developing and maintaining manuals on how to prepare computer programs to be placed in

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* See Figure 1.

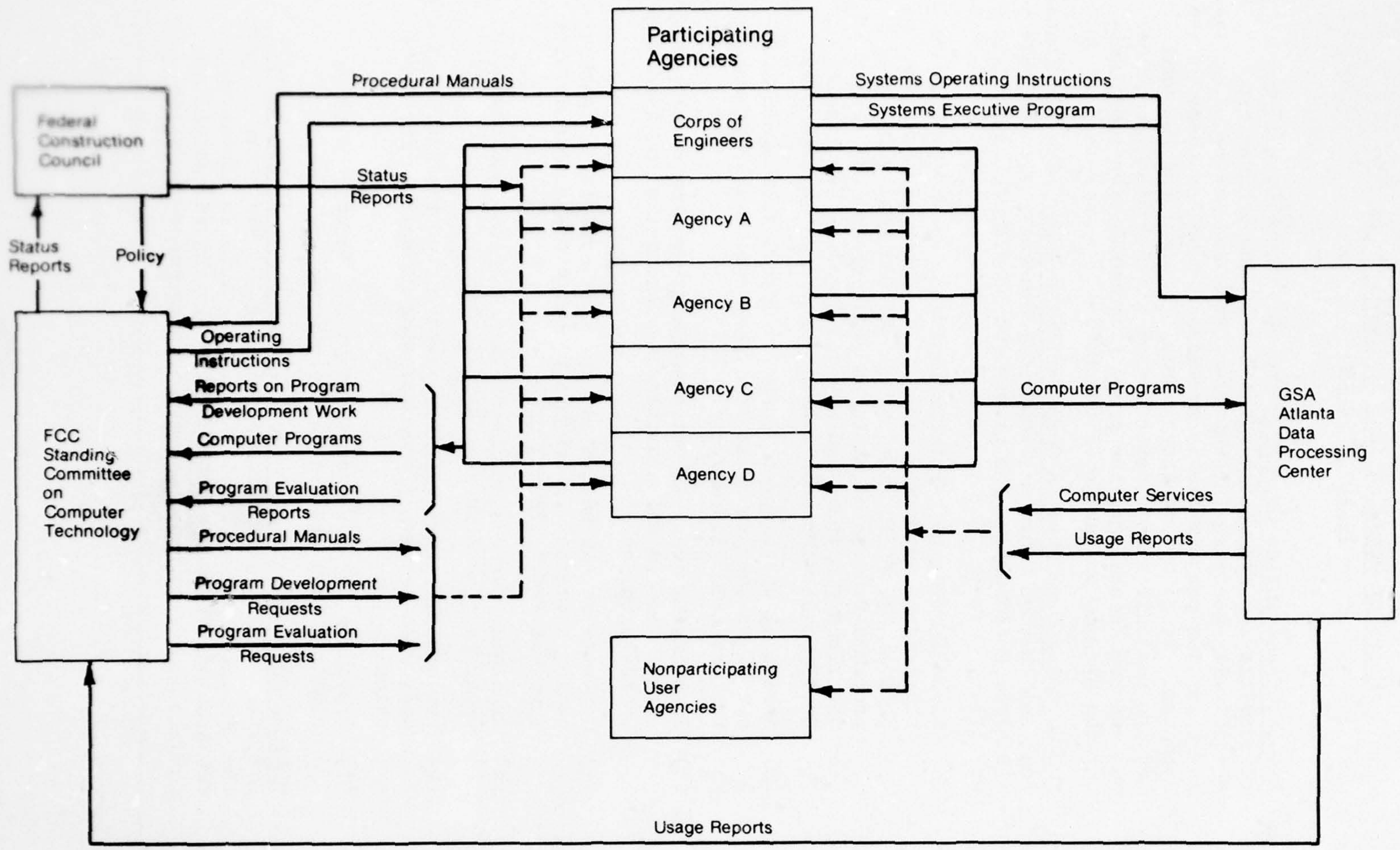

Figure 1. Flow-of-information diagram

the library and on how to use the library, for directing (on behalf of the Standing Committee) the daily operation of the FACTS library, and for answering user questions during the start-up period.*

d. Participating agencies.** Each agency participating in the program will be expected to:

(1) Be a RAMUS subscriber.†

(2) Modify, in accordance with the instructions to be prepared by OCE, those computer programs it currently has that are selected for inclusion in the FACTS library.

(3) Coordinate its computer-program development work with other participating agencies through the FCC Standing Committee on Computer Technology.

(4) Assist in evaluating computer programs prepared by other agencies.

(5) Train its personnel in the use of the FACTS library and in the preparation of the programs for inclusion in the library (the FCC Standing Committee will provide training for a cadre of agency personnel).

(6) Publicize the existence of and promote the use of the FACTS library among its personnel.

e. GSA Atlanta Data Processing Center. The Atlanta Data Processing Center will store the FACTS library in its computer and will make it available to all Federal agencies through RAMUS, its time-sharing system. If deemed desirable in the future, the Center also may assume the administrative responsibilities of OCE in the program.††

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* Much of the development work for which OCE will be responsible has already been completed and OCE's basic task will be to adapt available material. The documents prepared by OCE will be made available to the central offices of Federal agencies through the FCC Standing Committee on Computer Technology.

** Initially, there will be five participating agencies: The Naval Facilities Engineering Command, the Public Building Service of GSA, the National Aeronautics and Space Administration, the Veterans Administration, and the Corps of Engineers.

† Agencies not presently subscribing to RAMUS can do so by contacting the GSA.

†† If the Atlanta Data Processing Center does assume these responsibilities, some means of reimbursement for services will have to be devised.

Procedures and Practices

a. Appointment of members to the Standing Committee on Computer Technology. Members of the Standing Committee on Computer Technology will be appointed in accordance with the usual procedures of the FCC; i.e., by the Chairman of the Building Research Advisory Board, based on nominations by Federal construction agencies, with the approval of the President of the National Academy of Sciences. All supporting agencies of the Council and all other Federal construction agencies participating in the program will be invited to nominate individuals for committee membership.

b. Eligibility requirements for agencies wishing to participate in the program. Any Federal agency directly responsible for construction that possesses a construction-related computer activity and indicates a willingness to carry out the duties of a participating agency will be eligible to participate in the program. (An agency would not be required to participate in all aspects of the program, such as submitting programs or reprogramming present programs, to use the FACTS library; the only essential requirement is that an agency be a RAMUS subscriber.)

c. Preparation and dissemination of required manuals. Manuals on preparing computer programs for incorporation in the FACTS library and on using the library will be prepared by OCE and will be reviewed and disseminated by the FCC Standing Committee on Computer Technology. After dissemination, the Committee will seek suggestions from users on improving the manuals and will arrange for the preparation of revisions when necessary.

d. Administration of the FACTS library. Acting on behalf of the FCC Standing Committee on Computer Technology, OCE will handle the day-to-day administration of the FACTS library including such matters as directing the placement of new programs in the library, instituting changes in the executive program, and answering inquiries from agencies regarding the operation of the FACTS library. (Inquiries about a specific program in the library will be referred to the agency that prepared the program.)

e. Selection of computer programs to be developed or adapted for use in the FACTS library. After initiation of the program and development of the required manuals, the FCC Standing Committee on Computer Technology will obtain documentation on the programs already in use at the various agencies. In consultation with specialists in the different engineering disciplines, the Committee will select, from among the programs available at each participating agency, those having broad applicability. It will submit to each participating agency

a request that it adapt the selected program for use in the FACTS library in accordance with the program preparation manual.* At the beginning of the second year of the program, or after a significant number of available computer programs have been adapted for use in the FACTS library, the Committee will, in consultation with specialists in the different engineering disciplines, identify engineering problems for which computer programs should be developed. The Committee then will request that the various participating agencies volunteer to develop one or more new programs for solving identified problems. This process will be repeated annually.** With regard to both adapting existing programs and developing new programs for use in the FACTS library, participating agencies will be free to undertake work other than that requested by the Standing Committee; however, agencies will be expected to give some priority to requested work and to keep the Committee informed of the status of program development work under way. Annually, the Standing Committee will prepare for dissemination by the FCC a report indicating program adaptation and development work scheduled, under way, and completed at the various agencies.

f. Composition of the FACTS library. The FACTS library will include programs dealing with all construction-related engineering disciplines. A directory of programs stored in the library will be maintained and periodically printed and distributed to users; users also will be able to obtain a printout of the directory from the computer, via time-sharing terminals. The FACTS library will not be stored as an entity in the Atlanta Data Processing Center computer. Rather, it will be stored as part of various other libraries in the computer (see Figure 2). Frequently used, widely applicable programs in the FACTS library will be stored in the general library section of the computer (to which all time-sharing customers have access); infrequently used programs in the FACTS library will be stored in the libraries of individual agencies. (Generally, an infrequently used program will be stored in the library of the agency that developed it.) This manner of storage will not adversely affect the user of the FACTS library since any program in the FACTS library will be available to a user regardless of where it is stored. Some agencies, however, might have special programs stored in their individual libraries that are not in the FACTS library, and other users would not have access to such programs. Actually, the storage arrangement for the library is important only

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* It is anticipated that approximately 100 currently available programs will be adapted for inclusion in the FACTS library within 1 yr.

** It is anticipated that in 5 yr the FACTS library will include at least 250 programs.

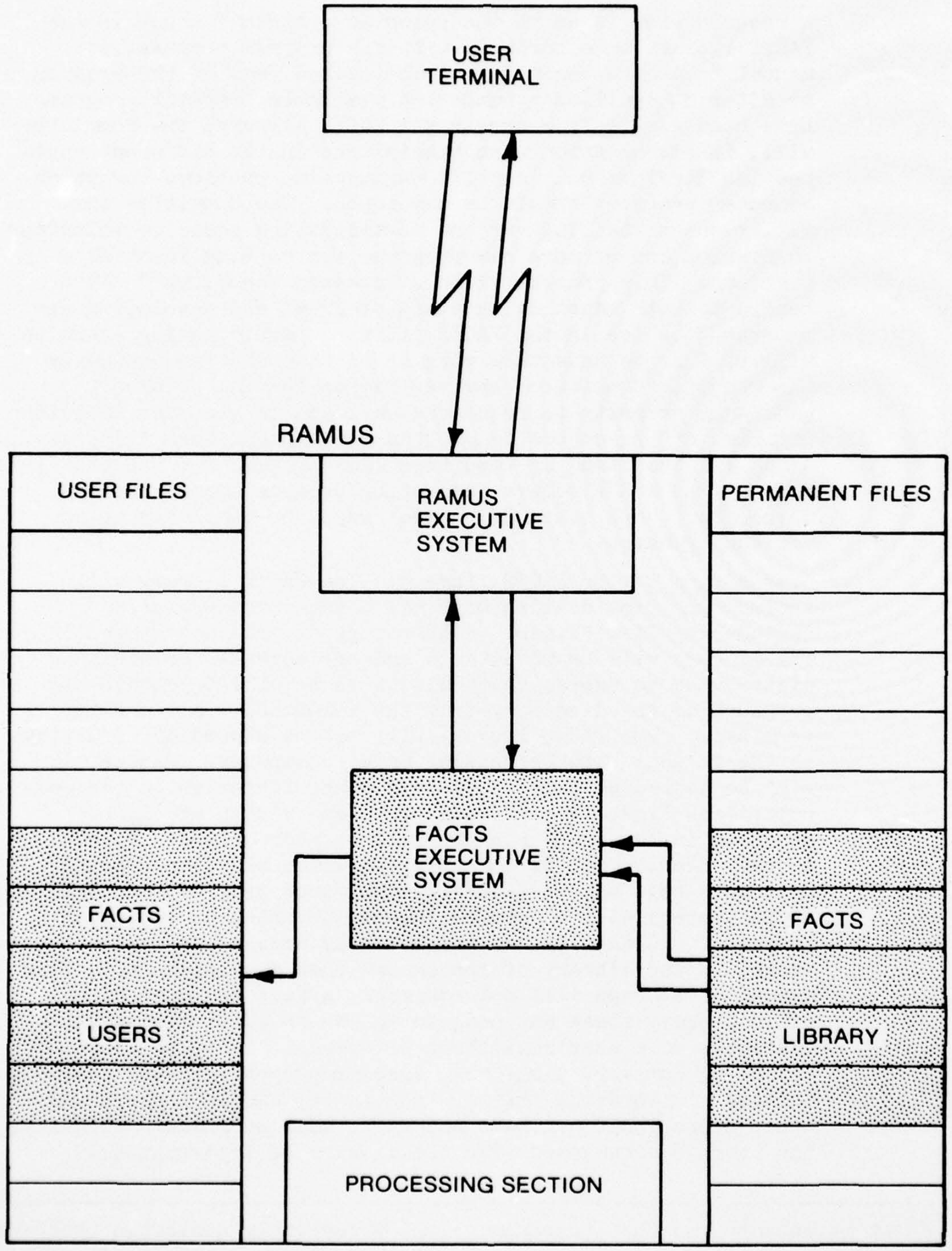

Figure 2. FACTS in relation to RAMUS

because it affects storage charges. The cost of storing programs in the general library section of the computer will be absorbed by the Atlanta Data Processing Center, whereas agencies will pay the standard RAMUS storage fee for programs stored in their individual libraries. The Atlanta Data Processing Center and the Standing Committee will jointly decide which programs are to be placed in the general library section. This determination will be made on the basis of frequency of use; a record of the number of times each program in the FACTS library is used will be maintained in the computer and a quarterly report on usage will be prepared for the agencies and the FCC by the Standing Committee.

g. Review and validation of computer programs. A two-step procedure will be used to ensure the technical validity of programs in the FACTS library. First, each program newly developed or adapted for inclusion in the FACTS library will be labeled an "unvalidated program" and users will be requested to comment to the FCC on the results obtained using it.* Second, after a new program has been in the library for 6 months to 1 year, the FCC Standing Committee on Computer Technology will ask a participating agency, other than the preparing agency, to evaluate the program. In evaluating a program, an agency will be expected to review comments received from users in addition to making an independent analysis of the program. The evaluating agency will be instructed to judge the technical validity of the program, the clarity of user instructions, and the appropriateness of the input and output formats. After completing its evaluation, the reviewing agency will be expected to submit a brief report of its findings to the Committee. If the reviewing agency finds no problems with the program, the "unvalidated program" label will be removed and the program will be considered fully approved. If the reviewing agency identifies problems with the program, the report of the reviewing agency will be sent to the preparing agency with a request that it consider correcting the identified faults. After correction of the identified faults, the revised program again will be placed in the library with or without the "unvalidated program" label, depending on the extent and nature of the changes made. If the revised program is labeled "unvalidated," the review process will be repeated. Should the reviewing agency and preparing agency disagree on the need for changes, the Standing Committee will mediate the dispute. If a mutually satisfactory solution cannot be found, the program may be retained indefinitely in the library with the "unvalidated program" label.

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* Users will be free to submit comments on any program in the library, but they will be specifically requested to submit comments only on unvalidated programs.

h. Training of programmers and users. Introduction of the system requires both the training of programmers to assemble the preambles necessary for each program, and the training of users. The Committee will conduct training workshops of both types for a cadre of personnel from each agency and this cadre will be responsible for dissemination of the information throughout that agency. After these initial workshops have been completed and evaluated, a series of "updating" workshops will be held as needed to discuss new innovations in the system, train personnel from new agencies, and provide additional training required by the original agencies.

Implementation Schedule

The overall program will become fully operational within one year of initiation. The schedule for carrying out the various start-up tasks during the first year is shown in Figure 3.

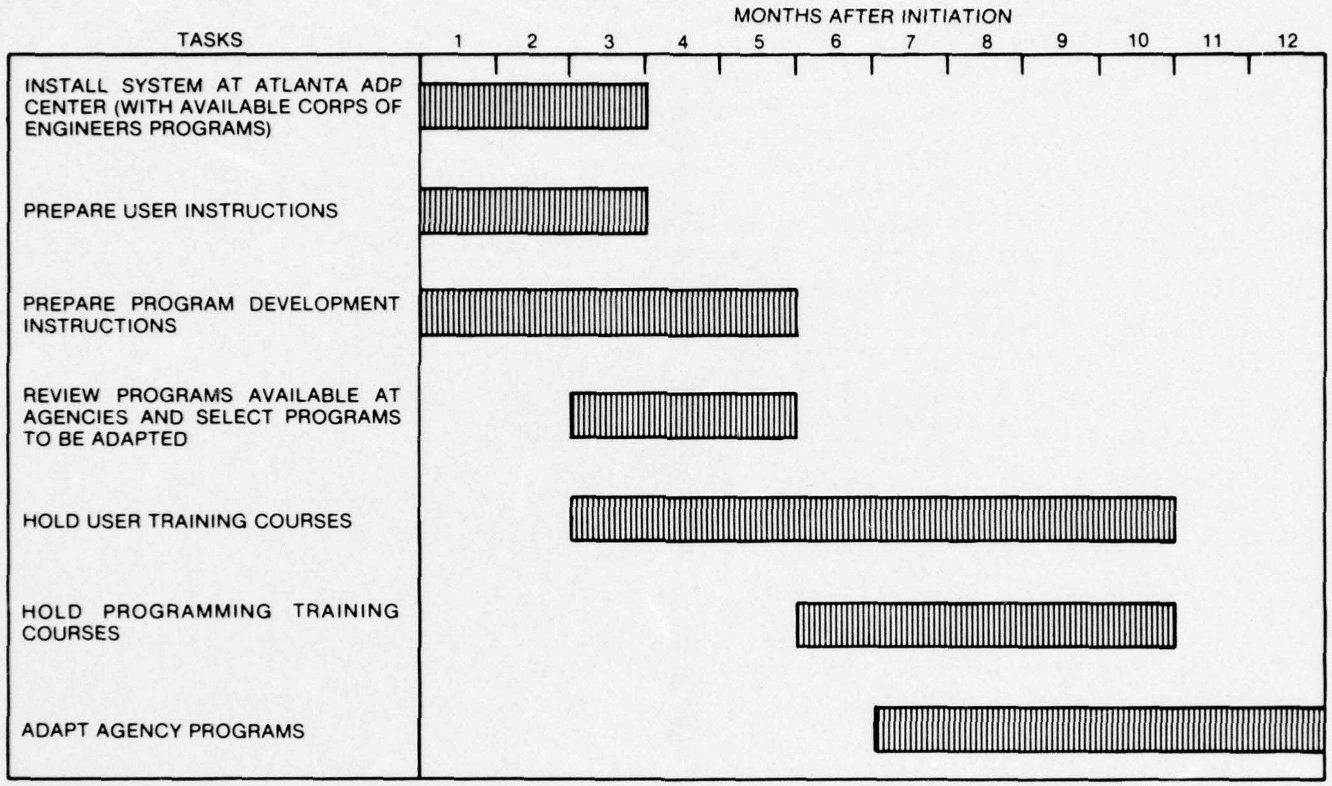

Figure 3. Implementation schedule

APPENDIX A: BIOGRAPHICAL SKETCHES OF AUTHORS

Mr. Charles F. Corns is the Chief Structural Engineer in the Civil Works Directorate of Office Chief of Engineers (OCE). In this capacity he is responsible for the review and approval of structural features of the Corps' water resources development program, the promulgation of design criteria and standards, and the surveillance of the Corps' structural research program.

Mr. Corns began his career with the Corps of Engineers in 1941 following graduation from Akron University with a Baccalaureate Degree in Civil Engineering. Except for a 3-yr absence for duty in the armed forces during World War II, he served in the Corps' Omaha District until 1961, principally as a specialist in structural and foundation problems associated with construction of the Missouri River Dams. Mr. Corns was named Assistant Chief of the Structural Branch, OCE, in 1961, and became the Branch Chief in 1965.

He is the current Chairman of the United States Committee on Large Dams and a member of the Reinforced Concrete Research Council (serving on the Executive Committee from 1971-1974). He is also a member of the American Society of Civil Engineers (ASCE), the American Concrete Institute, the American Society for Testing and Materials, and the American Society of Military Engineers. Mr. Corns is a registered professional engineer and a recipient of the Department of the Army's Meritorious Civilian Service Award.

COL Patrick W. Marks is currently assigned as Chief, EIDSO, OCE. He has earned his BS in Mechanical and Aeronautical Engineering from Texas A&M University and his MS in Management from American University, and is a registered Professional Engineer.

His previous Army tours were with the Joint Atomic Task Force tests in the Pacific, Army Polar R&D in Greenland, Atlas F & Titan II Construction Program for the Air Force Ballistic Missile Effort, and as Assistant Chief of Staff for Force Development on DA Staff, mainly concerned with the organization and testing of proposed new Army Divisions.

Mr. William D. Ashton is a Structural Design Engineer working with the Rock Island District, Corps of Engineers, Illinois. He has his BS and MS degrees in Civil Engineering from the University of Iowa. His

experience in the design area includes the structural inspection and evaluation of numerous navigation structures and highway and railroad bridges, design of several highway and railroad bridges, and other typical Corps of Engineers application areas. He has been very active in developing computer programs for design analysis and has taught several short courses on the "Stiffness Method of Structural Analysis." He is the author of numerous publications and is the joint author (with Dr. B. L. Meyers) of a book (to be published) on "Stiffness Method of Structural Analysis."

Mr. James Cheek, physicist, mathematician, manager, Chief, Computer Analysis Branch, Automatic Data Processing Center (ADPC), Waterways Experiment Station (WES), member of the ASCE Sub-Committee on Computer Practices within the Government, and the American Management Association, is a low-profile fellow whose pleasure is in helping his staff mature and broaden their professional capability and influence. He has been directly involved in engineering-scientific computer applications since 1958 with major emphasis on techniques and equipment which produce friendly, engineer-oriented, computer-aided design and analysis packages. He lectures on developments in interactive computer graphics and its impact on computer-aided design. He has some skill in the design and fabrication of small mechanical mechanisms, loves to hunt quail, pheasant, and duck, and is an enthusiastic dry fly fisherman.

Dr. N. Radhakrishnan (Radha) is the Special Technical Assistant and Research Civil Engineer with the ADPC, WES, since September 1969. He has his BS and MS degrees in Civil Engineering from India and his Ph. D. degree in Civil Engineering from the University of Texas at Austin, Texas. He has been a practitioner of the finite element technique for the past 8 yr and has applied the method to a wide variety of Corps' problems in the areas of foundations, soil structure interaction (static and dynamic), structures, etc. Dr. Radha is the author of several technical papers on the subject and is an invited lecturer for several forums. Dr. Radha has been teaching short courses for the Corps on a variety of topics including, "Application of Finite Element Method to Civil Engineering Problems," for the past several years. He was also

the Coordinator for the Corps-Wide Conference on Computer-Aided Design in Structural Engineering (CADSE) held in New Orleans in September 1975.

On 28 October 1975, Mr. Richard "Dick" Delyea died at age 47. The Corps of Engineers is diminished by his death.

Dick worked at headquarters, but he was not a "headquarters' man." His mind and heart were tied to the field engineer. We at WES knew him as Chief of the Computation and Analysis Branch of the Engineering Division at OCE. Through his constant urging to help the field people get their work done, the Corps' capability in engineering-computer technology has grown in many dimensions. Engineering Computer Notes, the Corps-Wide Conference on CADSE, the CORPS engineer-oriented programming system, the ECCAG computer standards and long-range plans, developments in interactive computer graphics, and computer models for Urban Studies are but a very few of the innovative activities which bear his Branch's mark.

But accomplishments tell only half the story. Dick was a gentleman, one of the good guys, who rose to the top of the heap through hard work, dedication, and circumspect behavior. He never lost sight of the reason for his advancement or the mission of his Branch. In spite of, perhaps because of, his rise to a position of major influence, he remained dedicated to the interests of the working-level engineer. In life and death he casts a clear light for those who follow.

We miss him. We mourn his untimely death. Yet we find ourselves inspired. Inspired to press on with the tasks he began and inspired by the fine example he set as a warm, friendly, compassionate gentleman, and a dedicated engineer.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Corps-Wide Conference on Computer-Aided Design in Structural Engineering, New Orleans, La., 1975.
[Proceedings ... held in New Orleans, Louisiana, 22-26 September 1975] Vicksburg, Miss., Automatic Data Processing Center, U. S. Army Engineer Waterways Experiment Station, 1976-
12 v. illus. 27 cm.
Contents.-v.1. Management report.-v.2. List of computer programs for CADSE.-v.3. Invited speeches and technical presentations.-v.4. Division presentations.-v.5. State-of-the-Corps-Art (SOCA) reports on gravity monoliths, U-frame locks, and channels.-v.6. SOCA reports on gates, stoplogs, and trashracks.-v.7. SOCA reports on single- and multiple-cell conduits and tunnels.-v.8. SOCA reports on pile foundations and sheet pile cells.-v.9. SOCA reports on sheet pile walls and T-walls.-v.10. SOCA reports on stiffness methods, frames, and military construction.-v.11. SOCA reports on earthquake and dynamic analyses.-v.12. Interactive graphics, SEARCH and CORPS systems.

(Continued on next card)

Corps-Wide Conference on Computer-Aided Design in Structural Engineering, New Orleans, La., 1975.
[Proceedings ...] 1976-
(Card 2)

1. Computer-aided design -- Congresses. 2. Design -- Congresses. 3. Structural engineering -- Congresses. I. U. S. Army. Corps of Engineers. II. U. S. Waterways Experiment Station, Vicksburg, Miss.
TA641.C67 1975